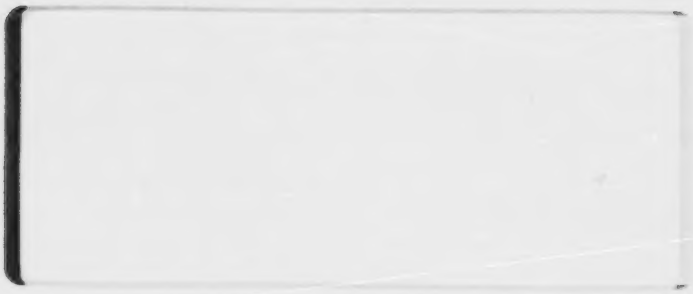

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LEVEL ICE PHYSICAL PROPERTIES IN SUPPORT OF THE M.V. ARCTIC PERFORMANCE TRIALS IN BAFFIN BAY AND ADMIRALTY INLET MAY-JUNE 1986

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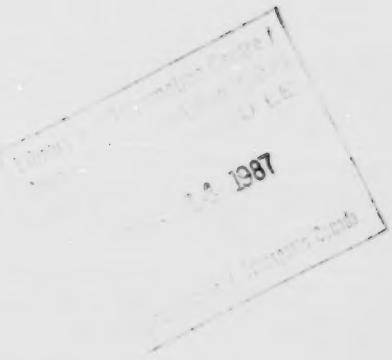

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17. Abstract

This report presents the results of on-ice work conducted in parallel with performance tests of the M.V. Arctic in Baffin Bay and Admiralty Inlet from mid-May to mid-June 1986. The work included the measurement of the ice physical properties of thickness, snow cover, temperature and salinity at selected stations in both geographic locations. Several profiles of a small pressure ridge in Admiralty Inlet were also made in support of a ridge penetration performance test of the M.V. Arctic.

Measurements were also made of the width of the ship's track in Admiralty Inlet as well as the distribution of ice piece sizes remaining along two sections of the track.

These data incorporate all related ice measurements made during the spring of 1986 M.V. Arctic performance tests and add to the database of ice properties related to ship performance.

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17. Résumé

Ce rapport décrit les travaux de caractérisation des glaces qui ont eu lieu dans la baie de Baffin et dans l'Inlet de l'Amirauté, de la mi-mai à la mi-juin 1986, parallèlement aux essais de performances à bord du N.M. Arctic. Ces travaux incluaient la mesure des propriétés physiques des glaces dans ces deux régions: épaisseur, enneigement, température et salinité dans des endroits choisis. Dans l'Inlet de l'Amirauté, plusieurs profils ont été obtenus d'une petite crête de pression en préparation des essais de charge auxquels l'Arctic devait être soumis.

Le chenal ouvert par le navire dans la glace de l'Inlet de l'Amirauté a été mesuré, ainsi que la distribution dimensionnelle des fragments observés en deux endroits différents.

Le résultat des campagnes de mesurage concernant les propriétés des glaces, menées parallèlement aux essais de performances au cours du printemps de 1986, servira à enrichir la base de données concernant les relations entre les propriétés des glaces et les performances du navire.

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Propriétés physiques, glaces de mer, N.M. Arctic, performances, mesure du chenal, pointes de fissuration.	Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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LEVEL ICE PHYSICAL PROPERTIES - IN SUPPORT OF THE M.V. ARCTIC PERFORMANCE TRIALS IN BAFFIN BAY AND ADMIRALTY INLET MAY - JUNE 1986

1. INTRODUCTION

In the spring of 1986, the M.V. Arctic was fitted with a new bow and structurally strengthened in order to up-grade the vessel to an Arctic class 4 equivalency and thereby permit an extended operating season. The new bow was designed by Melville Shipping Co. Ltd. of Ottawa and fitted at Port Weller. As part of the new bow design, Melville Shipping developed a computer model to predict the performance of the ship in its new configuration. A model of the ship was tested at model scale in three ice tanks around the world. To validate the Melville bow computer model and compare the model scale tests, Canarctic Shipping Co. Ltd., sponsored by the T[illegible]sportation Development Centre (TDC), of Transport Canad[illegible]roposed to test the performance of the vessel during its first Arctic voyage into the Nanisivik minesite in May/ June 1986.

To test the performance of the M.V. Arctic, the vessel was instrumented to measure the effects of ice impacts on the hull/girder structure. As well the ship propulsion system was instrumented to monitor ship performance in various ice conditions and transit modes. To support this shipboard instrumentation program and assist in interpretation of the ship transit performance, the sea-ice physical properties were required. Norland Science and Engineering Ltd. were sub-contracted to carry out the ice physical property program. This report presents the results of the on-ice work undertaken by Norland Science personnel in support of the M.V. Arctic performance tests.

1.1 Background

To carry out the ice physical property measurements, the Norland Science proposal included the execution of five main tasks as follows:

- Task 1 - Detailed experiment planning and logisitics arrangements
- Task 2 - Strategic assessment of ice conditions
- Task 3 - Baffin Bay and Admiralty Inlet performance tests

- o Task 4 - Admiralty Inlet pre-probe ice tests
- o Task 5 - Admiralty Inlet ship performance tests

Tasks 1 - 2 were completed before the field program commenced. The results of task 1 were presented in an interim report in May 1986 to Canarctic Shipping entitled "Experiment Plan for the Documentation of Ice Conditions at Admiralty Inlet and Baffin Bay". The findings of Task 2 were also presented at the same time in a report entitled "Assessment of Ice Conditions in Baffin Bay and Admiralty Inlet for the M.V. Arctic Performance Tests in Spring 1986".

Tasks 3 and 4 were carried out in Baffin Bay and Admiralty Inlet during the period May to June, 1986. Ice data were collected during the transit of Baffin Bay between May 31st and June 4th, and during the period May 26th to June 4th in Admiralty Inlet. Tasks 3 and 4 were completed when the M.V. Arctic arrived at the Admiralty Inlet ice shear edge on the evening of June 4th. Ice data continued to be collected under Task 5 during the in-bound voyage of the M.V. Arctic to the Nanisivik minesite. The M.V. Arctic arrived at the minesite on June 8th. The primary focus of this task was to assess the effect of the new bow on the ship track. This report presents the results of the on-ice work collected for Tasks 3 to 5.

The ice data collected in Baffin Bay and Admiralty Inlet for the physical property program consisted of the measurements of the ice characteristics along the ship route. In Admiralty Inlet more extensive ice measurements were done to characterize the northern part of the Inlet. The ice properties collected included:

salinity
temperature (in-situ, top 70 cm)
ice thickness
freeboard
snow depth
identification of ice type (e.g. first year)

In addition, one pressure ridge in Admiralty Inlet was profiled for its sail and keel geometry. Altogether 7 sites were measured in Baffin Bay and 53 sites in Admiralty Inlet. Of these 53 sites in Admiralty Inlet, only 12 sites were measured for all the parameters and the remaining were measured for ice thickness, freeboard and snow depth. In Baffin Bay, only 6 of the sites could be measured for all 6 parameters. At the other site only ice thickness, freeboard and snow depth were collected. Sections two and three of the report present the results in detail.

The ship track was characterized on the in-bound voyage during the period June 5th to June 8th. The principal focus of this part of the project was to study the ship's track to see if there were major differences in its shape, width and distribution of ice pieces. The track was analysed for the following measurements:

- o track width and cusp spacing
- o ice thickness and freeboard along the track
- o ice piece size and distribution
- o percent coverage of track with ice
- o photography of the track
- o video recording of the ship ramming the ridge.

Section four of the report presents the results of this work. A summary table of the ice parameters collected under each task is provided in **Table 1.1**.

During the in-bound voyage in Admiralty Inlet, data were also collected by Norland Science personnel on the ship track under a separate contract to Canarctic Shipping and Indian and Northern Affairs. Information was also obtained on the ship track characteristics in order to assess the effect of the ship track on the ice regime in Admiralty Inlet and the potential by the Inuit to cross the ship track for hunting. In order to carry out both projects, the personnel from the two teams joined forces during the period June 5th to June 8th. This enabled the efficient collection of the time dependent data. At the end of both programs the data were sorted out according to project and the relevant information handed over to the project leaders. It is believed that better data acquisition resulted by combining the two teams as both teams were fully aware of the value of the data to both projects, as well as the significance of the information. The data collected for Indian and Northern Affairs are to be presented under a separate report entitled "The Effects of Several Ship Tracks on the Ice Regime in Admiralty Inlet" (Norland Science report number 45) in November, 1986.

TABLE 1.1

SUMMARY OF ON-ICE TEST PROGRAM MEASUREMENTS

ICE PARAMETERS	BAFFIN BAY TASK 2	ADMIRALTY INLET TASK 3	TASK 4
Thickness, freeboard snow depth	x	x	
Salinity	x	x	
In-situ ice temperature	x	x	
Ridge profile		x	
Photography	x	x	x
Video recording	Collected under ice observation program		x
Ship track width, ice thickness along track			x
Ice piece size and distribution			x
Percent coverage of track with ice			x

1.2 Report Organization

This report is organized into 6 sections of which this introduction forms Section 1. Sections 2 and 3 present the results of the Baffin Bay and Admiralty Inlet field work (Tasks 3 and 4). Section 4 presents the ship track analysis (Task 5). Section 5 is a program summary. Section 6 provides the conclusions and recommendations. The references follow in Section 7. Appendices are presented at the end of the report. Included under separate covers are the field photo log book and the video log book.

2.0 BAFFIN BAY FIELD PROGRAM

2.1 Procedures

Level ice ship performance tests were conducted by Melville Shipping Ltd. and Canarctic Shipping Company Ltd. personnel in Baffin Bay between Disco Island and the entrance to Lancaster Sound near latitude 74°49' north and longitude 61° 60' west. The location of the tests as determined jointly between Canaric and Melville personnel according to criteria developed. A total of seven performance tests were carried out and fourteen data points collected. **Table 2.1** lists the performance tests conducted and the relevant ship speed, shaft power and ice flexural strength as reported by MelvilleShipping. **Figure 2-1** shows the location of the Baffin Bay tests.

Ice property data were gathered after the completion of each successful performance test. The data sets were collected at the start and end point of each run. Altogether seven data sets were obtained with each containing the following parameters:

- o ice thickness
- o freeboard
- o snow depth.

In addition, salinity and temperature were collected for six of the data sets. Photographs (35 mm film) were taken wherever time and field conditions permitted.

All seven data sets were obtained in generally level ice conditions. These sites were considered representative of the ice conditions in which the performance tests were conducted. In some instances the ship did traverse rubble areas during the course of testing. This resulted in slightly higher ice thickness values for the corresponding ice sites. A comparison of the ice thicknesses for each site reveals those thickness values drilled in rough spots. To avoid mis-representation of data values it was attempted to measure the "average" locations within these rough spots. **Plate 2-1** illustrates the level ice conditions found at site 2. Site 2 was established after a successful starboard channel breakout.

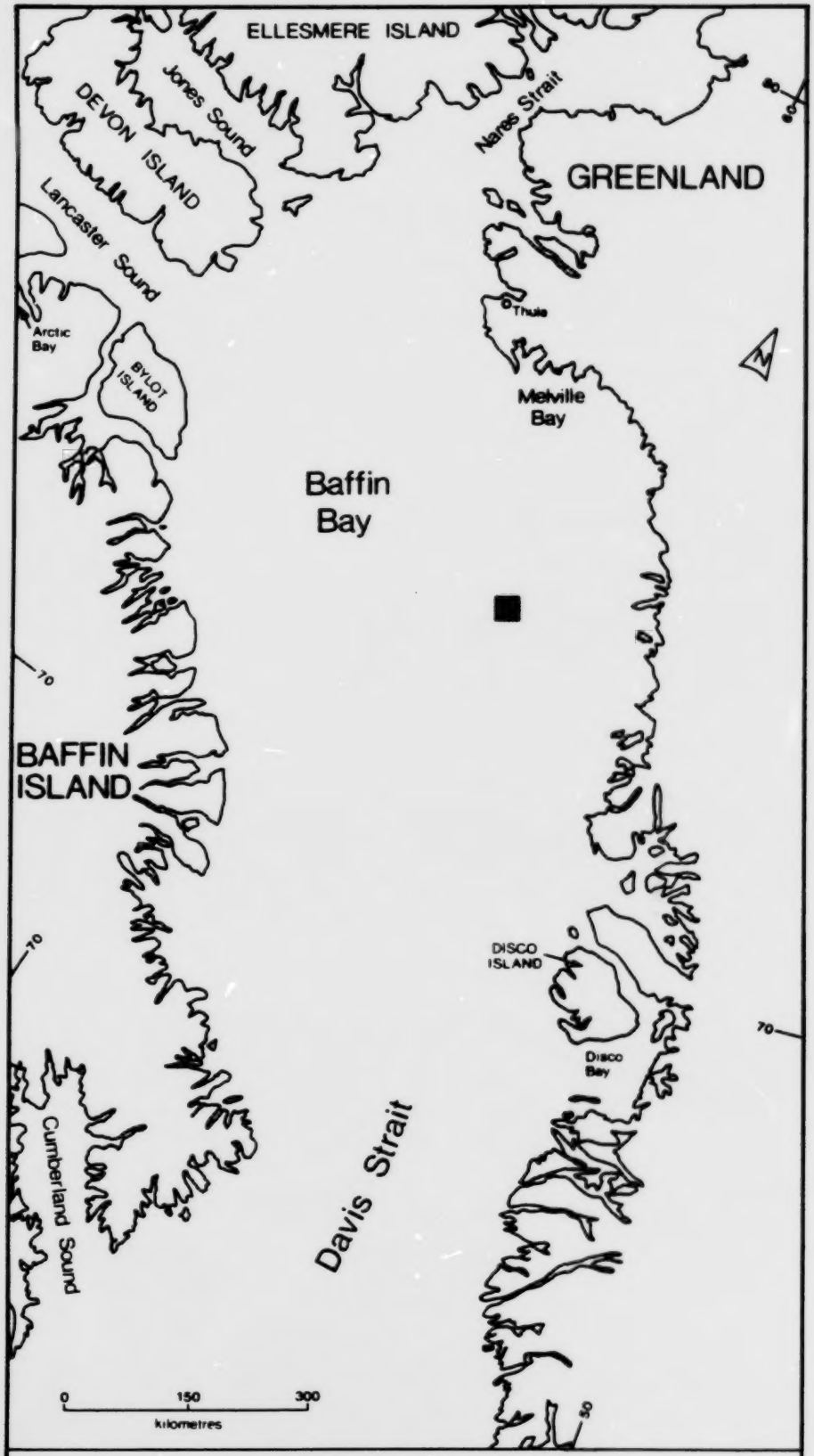
The on-ice data were collected using standard field equipment and techniques. The ice was drilled with a 4 inch auger and the thickness and freeboard measured with an Atmospheric Environment Service (AES) standard ice tape. Snow depth was obtained using a 1 meter, metal ruler. Four measurements were made per site and their values averaged for a representative number. Salinity cores were extracted using a SIPRE core barrel and transferred back to the ship in

TABLE 2.1

BAFFIN BAY SHIP PERFORMANCE TESTS*

TEST	MEAN SHIP SPEED IN ICE (KNOTS), $\bar{x}$	MEAN SHAFT POWER (kW), $\bar{x}$	MEAN ICE FLEXURAL STRENGTH (kPa)
Speed vs power in level ice (Test #6)	4.8 $\pm$ 2.6	7288.2 - 1932.3	253.4 $\pm$ 5.1
Broken Channel Acceleration (Test #7)	9.6 $\pm$ 0.5	10346 $\pm$ 73.5	307
Broken Channel Speed vs Power (Test #8)	11.6 $\pm$ 2.1	7949.4 $\pm$ 3364.5	297.2 $\pm$ 21.9
Channel breakout (Test #9)	5.3 $\pm$ 1.2	95578.8 $\pm$ 680.6	307
Turning circle (in ice) (Test #10)	4.5 $\pm$ 0.5	8527.7 $\pm$ 2257.3	254.7 $\pm$ 5.8
Control fixed directional stability (Test #11)	Conducted in water	-	-
Inertial Stop (Test #12)	5.9 $\pm$ 1.8	7300 $\pm$ 4384.1	257

* Melville Shipping Ltd. "M.V. Arctic Ship Performance Testing, Spring 1986" data extracted from Appendix 1.



BAFFIN BAY
DEDICATED ICE SITES

FIGURE 2-1

■ SITE LOCATION

PLATE 2-1

Level Ice Conditions at Site 2, Baffin Bay, June 1, 1986. Site 2 was established after a starboard channel breakout. Ice thickness 0.85 m, freeboard 0.05 m and snow depth 0.13 m.

labelled, sealed plastic bags for shipboard analysis. The cores were cut into discs at discrete intervals through the length of the core and stored in plastic containers for melt to room temperature. Each sample was then analyzed using an EDCO pocket refractive salinometer having an accuracy of +2 ppt. In-situ ice temperatures were obtained using a FLUKE thermometer probe. A block of ice was cut from the ice cover with chainsaws and the probe lowered at discrete intervals to a maximum depth of 0.70 m.

The time made available to the on-ice team was limited by the time required to conduct the ship performance tests. The field team had no means of over ice transportation, or of protecting themselves against the environment in case of an emergency. To collect the ice physical property data, it was required that the ship stop and wait for the field team to carry out their data measurements. Therefore it was necessary that the team remain in close proximity to the vessel during the field data collection. The field data collected was thereby limited to the 7 sites located along side the ship track. The data collected provided Melville Shipping personnel with sufficient information to classify the ice characteristics for input into their testing program.

Throughout the field work air temperatures were above -10°C and this created some concern with respect to brine drainage within the salinity cores upon extraction from the ice cover. To combat this problem the cores were processed as soon as possible.

2.2 Data Presentation and Analysis

The results of the field work are presented in the form of summary tables and figures. The complete set of salinity figures are presented in Appendix A with the exception of one graph included as a representative example in the main report. The average salinity values with depth tables for each site are also presented in the Appendix. Table A.2 and Figures A-1 to A-7 contain the relevant data.

Table 2.2 presents a summary of the ice physical properties measured at the seven sites. In addition, the calculated flexural strength of the ice is presented with the summary. The values were calculated using a method presented in a paper by CRREL researchers. The paper was provided by Melville Shipping Ltd. and was the method used by them for their flexural strength calculations. The method involves using two equations developed by Frankenstein and Garner (1967) and Weeks and Assur (1967). The first equation concerns the relationship of brine content to mean ice

TABLE 2.2

ICE PHYSICAL PROPERTY DATA - SUMMARY

BAFFIN BAY

SITE	1	2	3a	3b	4	5a	6a	7*
Ice Thickness (m)	1.02	0.85	0.86	1.63	0.98	1.14	1.00	0.71
Freeboard (m)	0.04	0.05	0.02	0.13	0.08	0.11	0.05	0.06
Snow Depth (m)	0.12	0.13	0.18	0.18	0.15	0.15	0.25	0.04
Average Salinity (o/oo)	5.2	---	5.6	4.9	5.7	5.8	5.3	4.5
Average Temperature (^{o}C)	-2.0	---	-2.1	---	-2.2	-2.1	-1.9	-1.3
Flexural Strength (kPa)	297.6	---	293.2	---	297.9	287.2	285.9	249.4

*At entrance to Admiralty Inlet

salinity and temperature, and the second equation defines the relationship of flexural strength of sea ice to the flexural strength of fresh water ice and brine volume. A detailed description of the equations are contained in Weeks and Assur "The Mechanical Properties of Sea Ice", CRREL monograph, September 1967. The equation used to calculate the flexural strength is presented in Table A.1 in Appendix A.

Ice Thickness

It was found that the ice cover of the tests sites varied in thickness between 0.85 and 1.63m with an average value for the sites of 1.02 ± 0.28m. The higher values recorded at sites 1, 3b, 5a and 6a represent ice thicknesses drilled in rough areas. Snow depth averaged between 0.04 and 0.25m with an average value of 0.15m. All the sites consisted of first year ice under early spring melt conditions.

Salinity

Ice salinity was measured in the top 1 m for 6 of the test sites. The values were found to vary from 4.5 to 5.8 ppt with an average salinity value for all the sites combined of 5.23 ± 0.5 ppt. In general, salinity was found to be higher in the top 0.10 m of the ice cover. The exceptions were at sites 3a, 4, and 5 wherein the salinity values were slightly (1 - 3%) higher at the lower depths. It is thought that this may reflect the effects of warm temperatures and brine drainage. Values differing by only 1% are believed to be the result of experimental error, as this value is within the error range of the salinometer used by the Baffin Bay team.

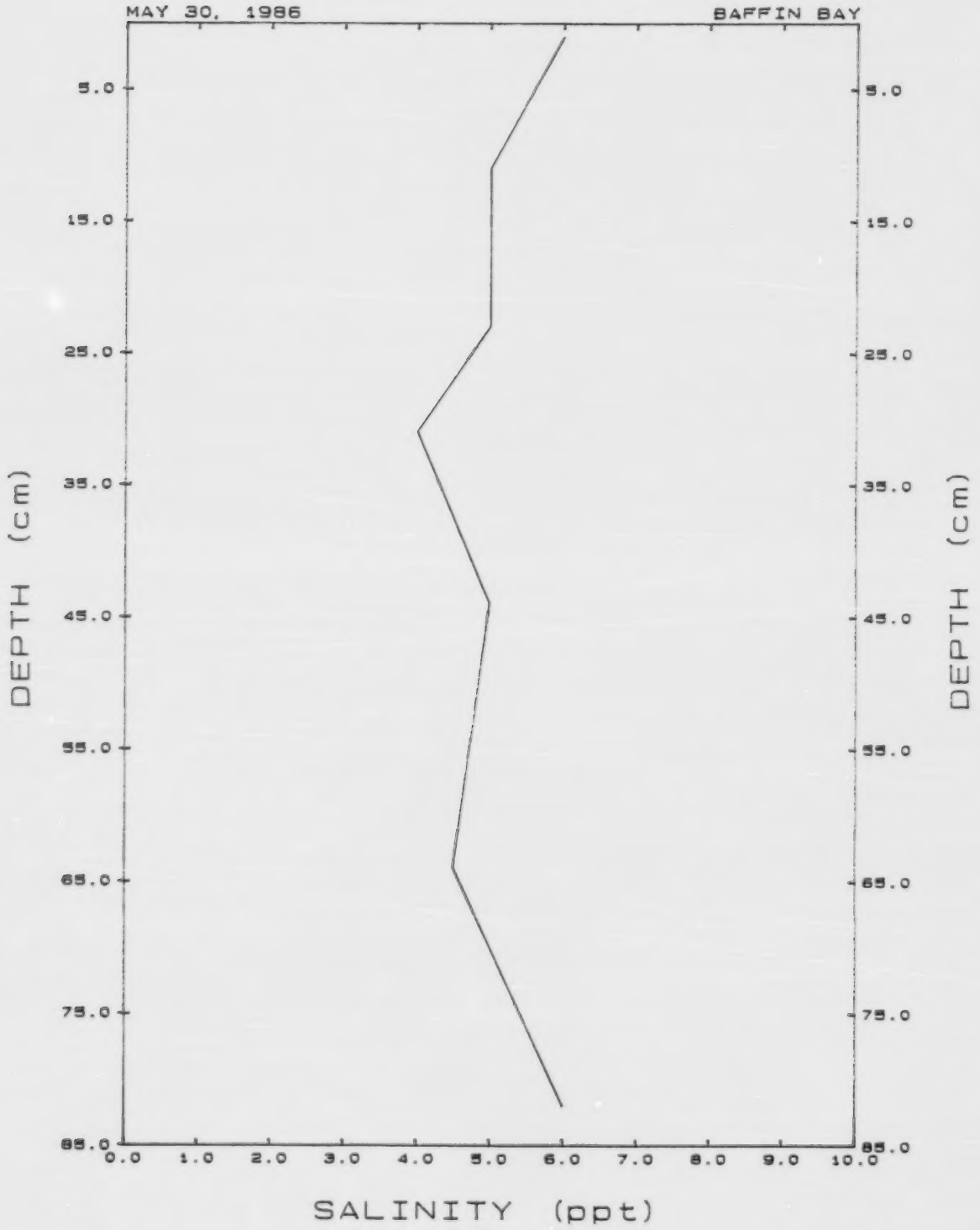
A typical example of the salinity profiles found for the data analysis is shown in **Figure 2-2** for site 3b. The profile illustrates a fairly uniform salinity for the length of the profile with variations of less than 2 ppt. The average salinity values for the core sample were as follows:

0.00 - 0.10 m: 5.5 ± 0.7 ppt
0.10 - 0.50 m: 4.7 ± 0.6 ppt
0.50 - 0.83 m: 5.3 ± 1.1 ppt.

The slight increase at the lower depth is believed to be a result of brine drainage which might have occurred after the core was extracted.

FIGURE 2-2

SALINITY VS DEPTH
SITE 3B



Flexural Strength

The flexural strength of the ice was calculated using the equations in Table A.1 for all the sites except sites 2 and 3b where insufficient field data prevented the calculation of the equation. It was found that the flexural strength varied between 249.4 to 297.7 kPa. The lowest value was found to be at site 7 which was located close to the Admiralty Inlet shear zone. The ice here was only 0.71m thick and had salinity and temperature characteristics typical of ice undergoing the spring warm-up.

In simple terms, the flexural properties of the ice can be related to the amount of voids (brine and air) in the sample ice used in the test. Once the relative volumes of the major components of ice are established, it is necessary to understand the structural considerations (texture and fabric) that control the distribution of the brine and air within the ice. The growth pattern of the ice (crystal formation and alignment), and its state of growth (aging process) at time of testing all influence the flexural ice strength. The values calculated for the Baffin Bay ice reflect first year ice under spring conditions.

3.0 ADMIRALTY INLET PRE-PROBE FIELD PROGRAM

3.1 Ice Conditions

To assist the field team in selecting ice sites for analysis, a February 6th STAR-1 SAR image of Admiralty Inlet was used. This permitted the team to easily negotiate the ice cover by helicopter and aided in the quick and accurate identification (and location) of the rough areas and old ice floes.

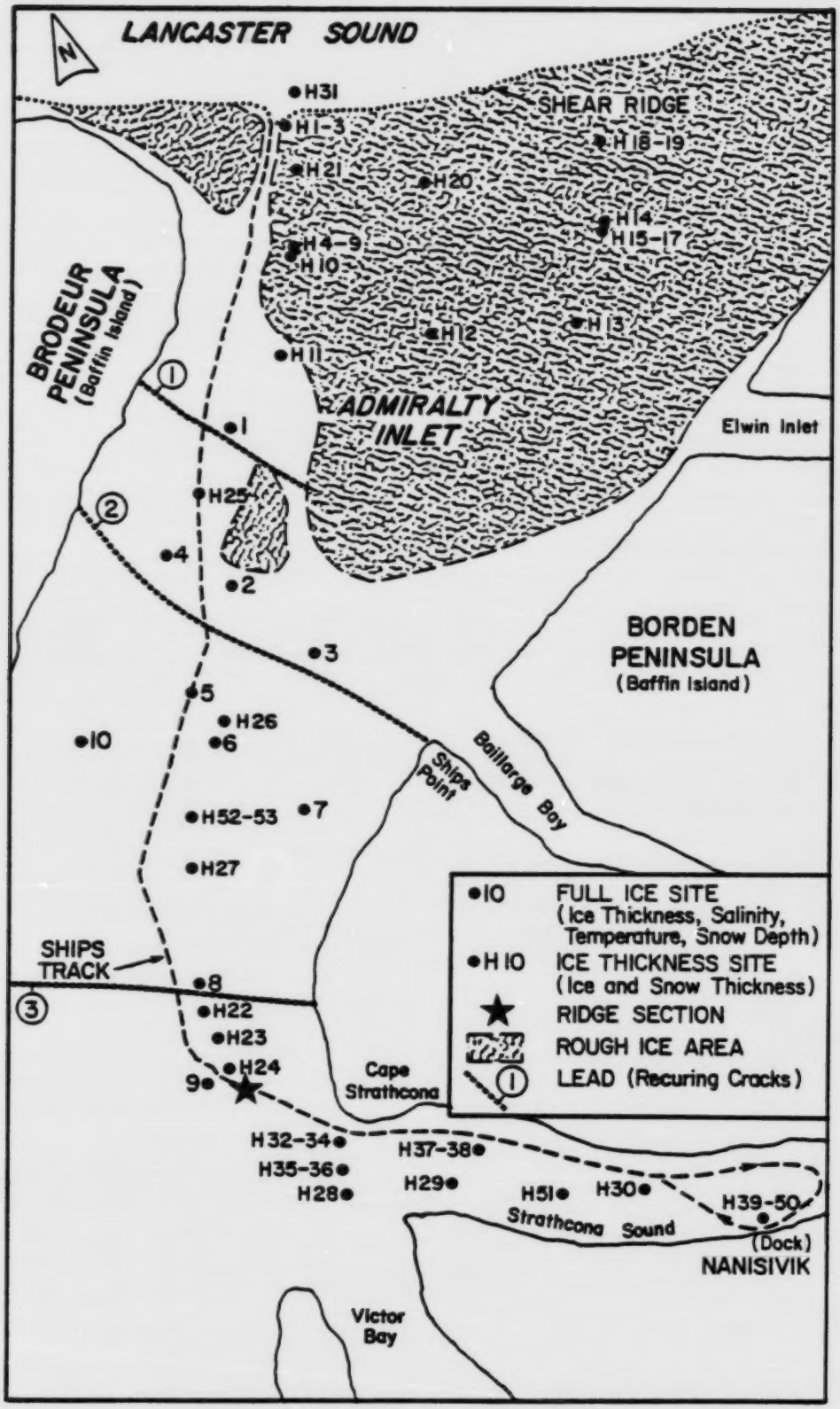
From the combination of SAR imagery and on-ice field tests the field team was able to successfully categorize the ice cover. As anticipated by the task 2 assessment, the ice cover was consolidated up to the minesite. Both Admiralty Inlet and Strathcona Sound consisted of first year ice with numerous patches of old ice floes located on the south side of the entrace to Strathcona Sound and in the rough zone situated at the entrance to Admiralty Inlet on the east side. Within the rough zone along Elwin Inlet several smooth lead areas identified in task 2 were located. These leads were former edges of the consolidated ice edge. **Figure 3-1** shows the location of the main ice features.

The recurring leads off Baillarge Bay and Cape Strathcona were readily visible from the air. These leads were less than 2m wide and slightly open along the east shore when the field team arrived on May 23rd. The leads became completely open along their length as far as the west shore by the time the M.V. Arctic arrived on site on the evening of June 4th.

Plate 3-1 is a west view of the lead located 100 m south of site 8. The lead was only slightly open along its north edge for a short distance west of site 8. The snow contours illustrate the full width of the lead. By June 4th the lead was completely open, but not to its maximum width.

Within the rough first year ice, the network of bright returns were identified as up-turned ice blocks covered by snow. From the helicopter these blocks did not appear to be very high, but in fact were up to 2 m in height. Several ice thickness sites were drilled in this zone (H13 - H19) and values averaged over 1.80 m, except in the leads, wherein the values were 1.60 m.

Plates 3-2 and 3-3 illustrate the surface roughness of the area. Plate 3-2 shows the upturned blocks at site H15. These blocks were grey-white ice pieces covered by over 0.20 m of snow. Plate 3-3 is an old ice floe located near site H17. The floe was over 15m in diameter and had numeorus rafted ice pieces imbedded around its perimeter. Snow drifting around the blocks was quite extensive.



LOCATION OF ICE SITES IN ADMIRALTY INLET

PLATE 3-1: West View of Lead 2 Located at 100 m South of Site 8, May 24, 1986.

PLATE 3-2: Surface Roughness Within the Rough Zone Located at the East Entrance to Admiralty Inlet. The ice blocks were grey-white ice pieces covered by 0.28 m of snow.

PLATE 3-3

Old Ice Floe Near Site H17 in Rough Zone Located at the Entrance to Admiralty Inlet.

As expected, there were few ridges in the ice cover in both Admiralty Inlet and Strathcona Sound. Of the three potential ridges identified in Task 2, only ridge 1 was acceptable. This was the shear ridge located near the entrance to Strathcona Sound and is identified in Figure 3-1. The ridge was situated along the proposed ship route (selected under Task 2) and was oriented in an northeast-southwest direction for over 2 km.

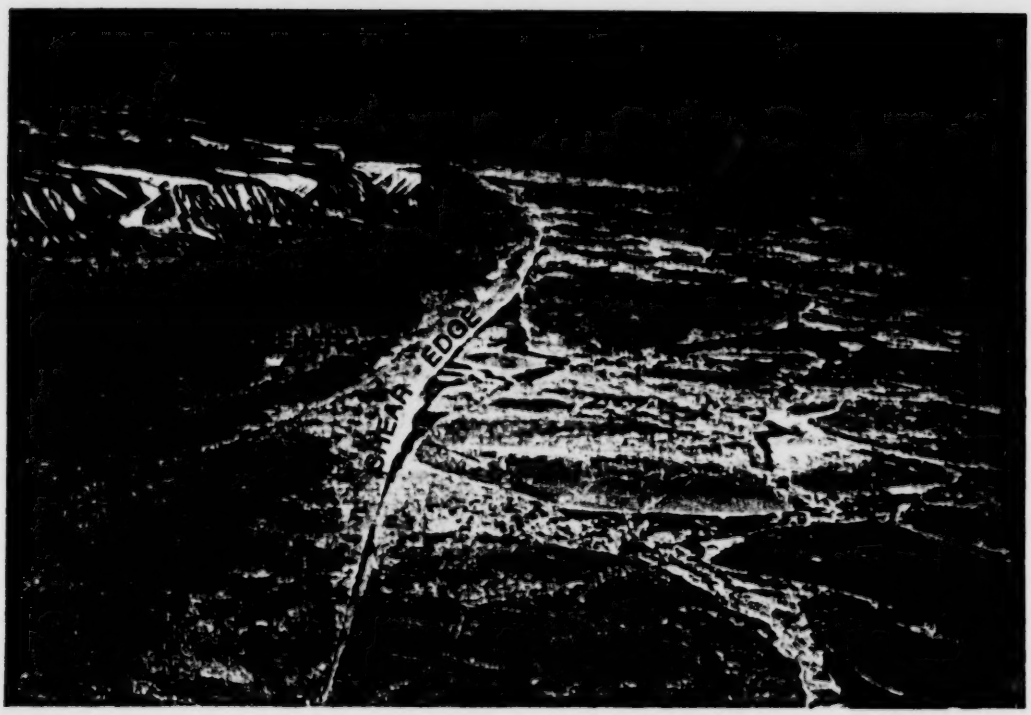
After compilation of all the field data, the field team confirmed the ideal ship route as the route selected in the task 2 assessment. This route entered Admiralty Inlet in the smooth zone located off the west shore and continued south following the smooth ice zone as far as Cape Strathcona. At this point the route gradually swung east towards Strathcona Sound, crossing the ridge at its optimum depth point. The M.V. Arctic successfully negotiated the proposed route with only a minimum of trouble at the Admiralty Inlet shear edge.

The ice conditions at the shear edge at the beginning of the pre-probe program consisted of a smooth edge with patches of open water and large pans of level ice. Approximately 5km from Cape Crauford was a large grounded iceberg in the matrix. At 3km east of the iceberg the optimum vessel entry point was identified based on the surface roughness characteristics. Had these ice conditions persisted, the entrance into Admiralty Inlet would have proven to be very easy for the M.V. Arctic. Instead, on-shore winds caused 2m high ice rubble piles along the length of the shear edge and across the optimum entry point. These ice conditions caused a formidable barrier to entry and the M.V. Arctic, due both to communication problems and the ice conditions, was forced to ram for over 4 hours along the shear edge towards the entry point before it could gain access into Admiralty Inlet. The ship had entered the shear zone well east of the optimum entry point due to communications problems and so was forced to ram along the shear edge towards the entry point. The ship passage is discussed further in Section 4.0. Figure 3-1 indicates the inbound ship track.

Plates 3-4 to 3-7 illustrate the sequence of ice events that occurred at the shear edge during the time period. Plates 3-4 and 3-5 show the ice conditions as they were for May 25th. The shear edge was smooth with no rubble and a matrix of open water with large, flat ice pans existed. The iceberg which marked the entrance area is visible in both photos. Plate 3-5 is a close-up of the iceberg looking eastward. The optimum entry point was located 3km east of the iceberg.

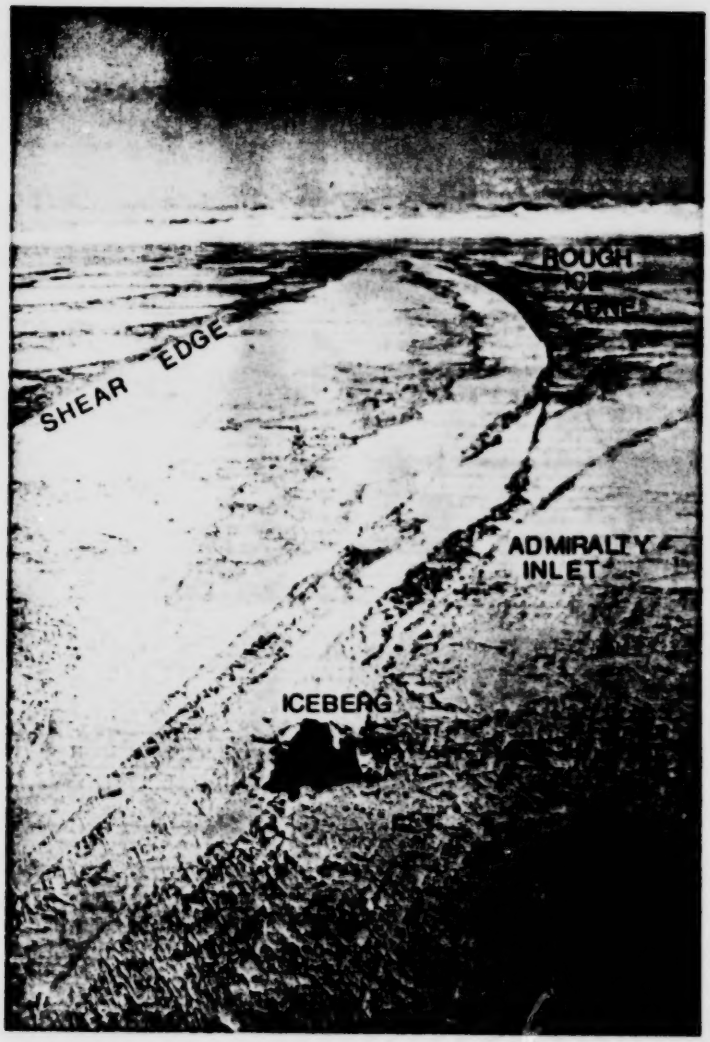
Plates 3-6 and 3-7 illustrate the change in conditions that occurred at the shear edge around June 2nd. On-shore winds from Lancaster Sound caused the extensive rubbling shown in

PLATE 3-4



West View Ice Conditions for May 25th along the Shear Edge at Admiralty Inlet. The edge was smooth with no rubbling. Patches of open water are visible between the ice floes.

PLATE 3-5



East View of Ice Conditions along Admiralty Inlet Shear Edge, May 23rd, 1986. Patches of open water are visible along the edge.

PLATE 3-6: Ice Conditions Along Admiralty Inlet Shear Edge for June 2, 1986. On shore winds had caused 2 m high rubble piles all along the edge. The photo is a southeast view.

PLATE 3-7: Ice Conditions Around the Marker Erected to Indicate the Optimum Ship Entry Point. The marker was 3 m high and erected 3 km east of the iceberg on the west shore.

Plate 3-6. The mobile ice floes had pushed up against the shear edge and created 2 m high rubble piles. The aerial view in the photo is taken looking southwards into Admiralty Inlet. Plate 3-7 is a ground perspective looking west along the edge at the optimum entry point. The marker was erected to assist the ship in finding the entry point. The marker was 3 m high and visible from a distance of 3 km at a height of 30 m.

3.2 Procedures

A field team arrived 10 days prior to the arrival of the M.V. Arctic in order to characterize the ice conditions within the Inlet and confirm the final ship route selection recommended in Task 2 of the project. The ice data collected during this period represents the Task 4 program and are presented in this section. The data collected during the performance tests are presented in Section 4.0.

A total of 53 sites were measured in order to characterize the ice cover in Admiralty Inlet and Strathcona Sound. Of the 53 sites, 12 were measured in detail for the following parameters:

- ice thickness
- freeboard
- snow depth
- salinity
- in-situ temperature (top 0.70 m only).

At the remaining 41 sites only ice thickness, freeboard and snow depth were measured. Figure 3-1 illustrates the location of the ice sites and their nomenclature. These data sets were used to recommend the ultimate ship route.

In addition to the sample sites, a 300 m portion of a shear ridge located near the mouth of Strathcona Sound was selected for the ramming tests to be conducted under the Task 5 data collection. The sail height and keel depth was profiled at ten locations spaced at 30 m intervals along the ridge axis to produce a detailed profile of the sail height and keel depth variability. A 30 m spacing was chosen as it closely approximated the width of the ship. A profile of the ridge sail was also made along the ridge axis between the ten 30 m cross-sections to obtain a detailed profile of the extent of the ridge sail. The ridge was surveyed on both east and west sides, up to a 30 m distance from the crown line. A total of 180 holes were drilled to measure the sail height and keel depth. This work was completed before the ship arrived.

To complete the ridge analysis, two representative cores were extracted from the ridge at two separate locations and analyzed for salinity. The top 2 m of the cores were processed. In-situ temperatures were also recorded at the two sites.

All ice data were collected using standard field equipment and techniques as described in Section 2.1.

3.3 Data Presentation and Analysis

The results of the field work are presented in the form of summary tables and figures. The complete set of salinity graphs are presented in Appendix B with the exception of one graph included as an example in the main text. The average salinity values with depth tables for each full site are also presented in Appendix B. Figures B-1 to B-12 contain the salinity graphs and Table B.1 presents the summary tables of average salinity vs. depth.

Table 3.1 presents a summary of the ice physical properties measured at the 12 full sites plus the ridge. The flexural strength was calculated for these sites and the values included with the table. Sites 46 and 51 represent the data collected in Strathcona Sound.

Ice and Snow Thickness

It was found that the ice thickness cover of Admiralty Inlet varied between 1.64 and 1.84 m with an average value for all the sites of 1.75 $\pm$ 0.1 m. It was observed that the ice cover seemed to be 0.20m thinner in a zone between sites 5 and 8 and extending west as far as site 10. **Table 3.2** presents a thickness summary of all the sites drilled in Admiralty Inlet. Close to the shear edge, ice thickness values averaged 1.0m with a value of 2.03 m recorded at sites H1-3 located right at the shear edge. At a distance of 0.3 km south from sites H1-3 the ice thickness at site H31 was measured to be only 0.66m. At an additional 3.0 km south (H21) from the shear edge the ice thicknesses were more uniform with values ranging from 1.69 to 1.87 m. This range of thickness values were characteristic of the Admiralty Inlet ice cover.

Plate 3-8 illustrates the ice conditions at site 2 for May 24th. The ice cover was feature-less and even on a good day it was difficult to re-locate the ice sites. Each site was marked by garbage bags and spray paint but they were still not readily visible from the air until the helicopter was almost over the site. The ice thickness at site 2 was 1.76 m, freeboard was 0.08 m and the snow depth was 0.16 m.

ICE PHYSICAL PROPERTY DATA - SUMMARY
ADMIRALTY INLET

SITE	1	2	3	4	5	6	7	8	9	10	46*	51*	SHEAR RIDGE (survey line 3 south)
Ice Thickness (m)	1.75	1.76	1.81	1.83	1.66	1.80	1.84	1.64	1.75	1.64	1.54	1.55	3.20
Freeboard (m)	0.07	0.08	0.12	0.10	0.10	0.10	0.11	0.10	0.08	0.06	0.12	0.07	0.22
Snow Depth (m)	0.24	0.16	0.16	0.17	0.18	0.19	0.23	0.23	0.28	0.23	0.08	0.05	0.45
Av.Salinity (0/00)	3.9	4.4	5.2	4.9	4.4	4.6	5.5	5.2	4.9	4.9	4.5	3.9	4.01
Av.Temp. (°C)(ice)	-4.9	-4.3	-6.4	-4.8	-4.4	-5.0	-5.5	-5.3	-5.1	-5.6	-2.6	-3.5	-3.8
Flexural strength (kPa) Melville Shipping	463	433	459	433	436	446	435	437	440	451	362	423	430

Admiralty Inlet = 443.3
= 10.67

*Cape Strathcona Sites

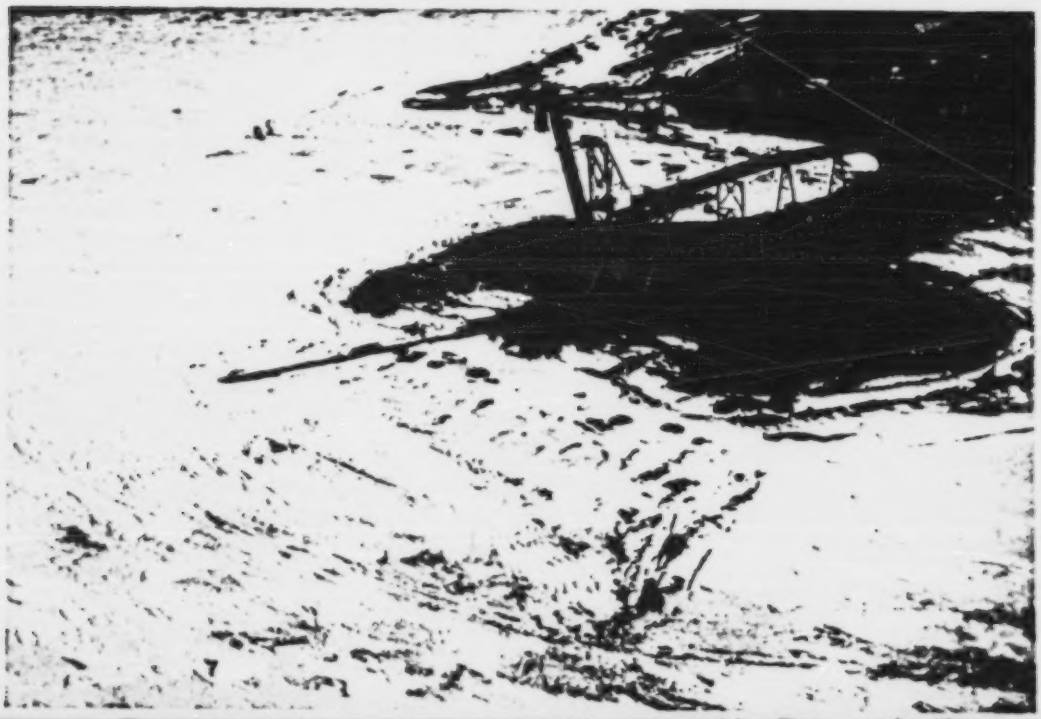
TABLE 3.2

ADMIRALTY INLET ICE THICKNESS SUMMARY

SITE NO.	ICE THICKNESS (m)	SNOW DEPTH (m)	FREEBOARD (m)
1	1.75	0.24	0.07
2	1.76	0.16	0.08
3	1.81	0.16	0.12
4	1.83	0.17	0.10
5	1.66	0.18	0.10
6	1.80	0.19	0.10
7	1.84	0.23	0.11
8	1.64	0.23	0.10
9	1.75	0.08	0.23
10	1.64	0.06	0.23
H1-3 ($\bar{x}$)	2.03	0.07	0.22
H4-9 ($\bar{x}$)	1.94	0.35	0.08
H10	1.27	0.16	0.06
H11	1.52	0.16	0.09
H12	1.82	0.09	0.14
H13	1.81	0.11	0.13
H14	1.82	---	0.16
H15-17($\bar{x}$)	1.87	0.28	0.03
H18-19($\bar{x}$)	1.68	---	0.14
H20	1.76	0.13	0.15
H21	1.69	0.14	0.10
H22	1.72	0.19	0.09
H23	1.80	0.12	0.11
H24	1.84	0.22	0.11
H25	1.78	0.11	0.09
H26	1.76	0.17	0.11
H27	1.58	0.22	0.07
H31	0.66	No Data	0.05
H52-53($\bar{x}$)	1.67	0.23	0.09

PLATE 3-8: Level Ice Conditions at Site 2 in Admiralty Inlet, May 24th, 1986. Ice thickness was 1.76 m, freeborad 0.08 m and snow depth was 0.16 m.

PLATE 3-9: Ice Conditions Around the Nanisivik Dock Site on May 25th, 1986. The black surface around the caissons is dirt that was spread on the snow cover to promote surface melt.



Ice thicknesses in Strathcona Sound were found to be noticeably less. The average ice thickness was 1.49 $\pm$ 0.1 m with freeboard values of 0.10 $\pm$ 0.03 m. **Table 3.3** presents a summary of the ice thicknesses measured down the length of the Sound. Thicknesses were found to be higher around the ice bussles which had formed around the caisson and in the rough zone at the entrance to the Sound.

Snow depths were greater in Admiralty Inlet than in Strathcona Sound. The snow cover in the Sound had undergone deterioration before the arrival of the field team and showed signs of melt. Snow depth values averaged 0.07 m within the centre of the Sound and only traces were recorded around the dock site. In Admiralty Inlet, snow depths averaged 0.21 m and consisted of hard packed granular snow. No visible deterioration of the snow cover was apparent in Admiralty Inlet until the first week of June. The snow texture then gradually deteriorated to corn snow by the end of the test program.

Plate 3-9 highlights the snow and ice conditions around the docksite on May 25th. Dirt had been spread onto the ice to promote surface melt around the caissons. The black dots which fan out around the dock area are piles of dirt. Around the face of each caisson was a 3 m high ice bustle. Within the ice bustle the snow cover was non-existent and gravel protruded through the ice. The ice thickness sites H39-50 were located at 100 m intervals off the centre caisson.

Salinity

The salinity was measured in the top 1.75 m of the ice cover at the 12 full sites. The values were found to vary from 3.9 to 5.5 ppt with an average value for the sites of 4.7 $\pm$ 0.5 ppt. In general, salinity was higher for the top 0.10 m of the cores, decreasing slightly at the lower depths. The exceptions were sites 46 and 51 located in Strathcona Sound wherein the salinity was uniform throughout the ice thickness. A typical example of the salinity profiles found for the data analysis is shown in **Figure 3-2** for site 1 in Admiralty Inlet.

The increase in salinity near the ice surface is caused by the expulsion of brine during the initial stages of ice growth in the fall. After the ice reaches a certain thickness, around 10 cm, the brine can no longer be expelled through the ice surface. Instead it is rejected at the ice-water interface as it grows. The percentage of salt trapped in the ice depends on its growth rate - faster growth will trap more salt and result in higher salinity. The resulting salinity profile remains relatively static through

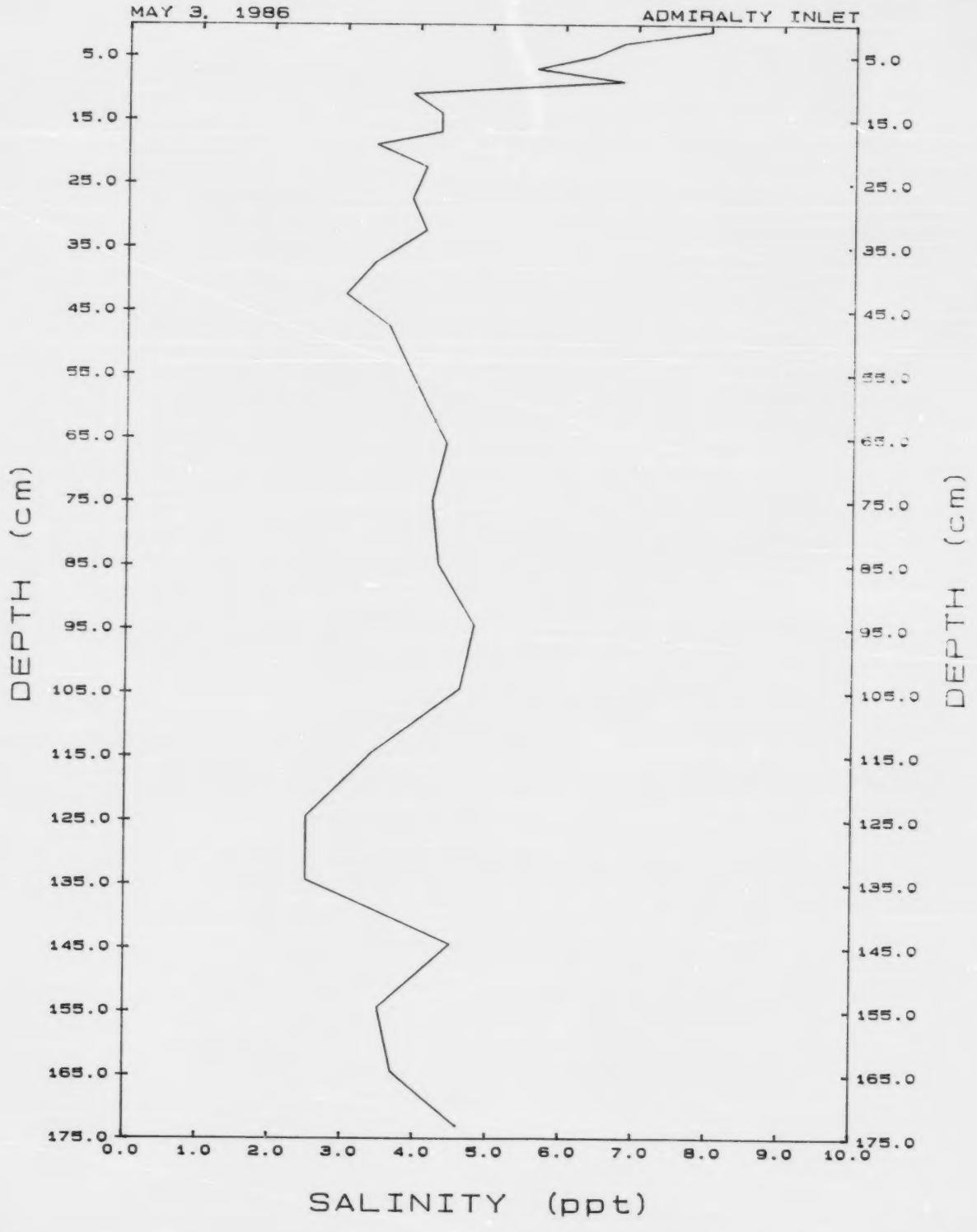
TABLE 3.3

STRATHCONA SOUND ICE THICKNESS SUMMARY

HOLE #	ICE THICKNESS (m)	FREEBOARD (m)	Location/Comments
H28	1.88	0.11	in rough zone at entrance
H29	1.58	0.10	East of H28
H30	1.50	0.08	East of H29
H32	1.84	0.15	In lead between 2 rough zones at entrance
H33	1.70	0.10	Next to H32
H34	1.98	0.07	Next to H33
H35	1.82	0.13	1 mile south of H34
H36	1.87	0.15	Next to H35
H37	1.50	0.02	East of H36
H38	1.61	0.08	Next to H37
H39	1.54,1.32	0.14,0.11	4 m from southern caisson
H40	1.52	0.15	40 m from centre caisson
H41	1.46	0.16	40 m from northern caisson
H42	1.77	>0.50	Centre caisson at 2nd bussle, tidal crack
H43	.20 ice .20 water .20 ice	-	10 m from centre caisson between first bussle and second bussle
H44	3.31	>0.50	1 m from centre caisson
H45	1.55	0.09	100 m from centre caisson
H46	1.54	0.12	100 m from H45 in direct north line
H47	1.48	0.12	100 m from H46
H48	1.43	0.08	100 m from H47
H49	1.46	0.11	100 m from H48
H50	1.46	0.11	100 m from H49
H51	1.55	0.07	4 miles west of docksite

FIGURE 3-2

SALINITY VS DEPTH
SITE 1



SAL1

the winter months, except that it extends down further as the ice grows. At the ice growth interface the salinity is always higher because the ice is still rejecting brine as it solidifies. This gives rise to a C-shaped salinity profile that is characteristic of first year ice during winter.

When the ice temperature begins to rise in the spring, the trapped brine in the ice begins to move down into the depths of the ice, slowly reducing the salinity in the upper sections of ice thickness. The first stage in the ice deterioration is a straightening of the C-curve to more of an L-shape. As the melt advances the salinity reduces to much lower values and, if the process is completed before the ice breaks apart, the salinity in the upper part of the ice can become zero.

Flexural Strength

The flexural strength of the ice was calculated for the 12 full sites using the Frankenstein adn Garner and Weeks and Assur equations provided in Appendix A, Table A.1. It was found that the flexural strength of the sample ice varied between 433 and 463 KPa with an average value of 443 $\pm$ 11 KPa. The lowest values (433 KPa) were calculated for sites 2 and 4 located to the west below the rough zone at the entrance to Admiralty Inlet, approximatley 28 km from the shear edge. Salinities and temperature values at these sites were slightly below those recorded for the other sites. The highest flexural strength value (463 KPa) was calculated for site 1. It was located 17km south of the shear edge close to a small ridge of consolidated ice blocks. The values obtained for the Admiralty Inlet data were observed to be about twice the flexural strength calculated for the Baffin Bay ice samples.

The flexural strength values calculated for the two Strathcona Sound sites were lower than those in Admiralty Inlet. Site 46 had a value of 362 KPa and site 51 had a value of 423 KPa. Site 46 was located 100m from the centre caisson of the dock and site 51 was situated in the centre of the Sound. The ice around the dock had started to deteriorate more rapidly thanthe ice in the centre of the Sound during the field program. Ice temperatures were between 2° and 3°C warmer in Strathcona Sound than they were for Admiralty Inlet. The lower flexural strength of the ice in Strathcona reflects the more advanced ice deterioration found in the ice cover.

Shear Ridge Geometry and Physical Properties

The shear ridge ice geometric properties were measured along 11 east - west survey lines. The results of the survey work are presented in **Table 3.4**. The salinity, temperature

TABLE 3.4

SHEAR RIDGE ICE PROPERTIES, SUMMARY TABLE OF ICE THICKNESS, FREEBOARD AND SNOW DEPTH

		DISTANCE (m) FROM CROWN ALONG SURVEY LINE													
LINE	ICE PROPERTY	30 WEST	20 WEST	10 WEST	6 WEST	4 WEST	2 WEST	0	1 EAST	2 EAST	4 EAST	6 EAST	10 EAST	20 EAST	30 EAST
0	Ice Thickness (m)	1.81	1.84	1.99	2.71	3.13	3.12	3.26	2.21	1.48	1.52	1.60	1.70	1.85	1.87
	Freeboard (m)	0.13	0.11	0.10	0.15	0.24	0.18	0.36	0.41	-0.07	-0.05	0.02	0.04	0.11	0.15
	Snow Depth (m)	0.11	0.16	0.27	0.39	0.39	0.40	0.24	0.46	0.63	0.51	0.51	0.29	0.16	0.18
1 South	Ice Thickness (m)	1.81	1.86	2.03	2.27	2.63	2.66	3.31	2.06	1.63	1.57	1.53	1.62	1.79	1.85
	Freeboard (m)	0.11	0.11	0.10	0.15	0.11	0.09	0.76	-0.02	-0.02	-0.05	-0.05	0.02	0.11	0.13
	Snow Depth (m)	0.24	0.28	0.33	0.36	0.34	0.39	0.28	0.55	0.63	0.62	0.68	0.43	0.21	0.29
2 South	Ice Thickness (m)	1.86	1.80	2.46	3.00	3.07	3.66	2.30	3.30	3.25	1.60	1.45	1.61	1.71	1.74
	Freeboard (m)	0.13	0.10	0.16	0.18	0.17	0.13	0.45	0.40	0.35	-0.01	-0.09	0.0	0.06	0.09
	Snow Depth (m)	0.13	0.27	0.31	0.31	0.39	0.47	0.45	0.36	0.60	0.66	0.63	0.55	0.26	0.27
3 South	Ice Thickness (m)	1.83	1.86	2.54	2.75	3.11	3.20	3.70	1.74	1.40	1.45	1.51	1.61	1.58	1.76
	Freeboard (m)	0.13	0.11	0.20	0.22	0.23	0.22	0.70	-0.09	-0.10	-0.05	-0.04	-0.01	0.03	0.11
	Snow Depth (m)	0.20	0.22	0.26	0.32	0.35	0.45	1.08	0.78	0.68	0.55	0.50	0.43	0.40	0.27
4 South	Ice Thickness (m)	1.84	1.76	2.80	2.40	2.69	2.80	3.67	3.45	1.47	1.42	1.43	1.54	1.71	1.80
	Freeboard (m)	0.10	0.08	0.18	0.15	0.14	0.19	0.62	0.15	-0.08	-0.06	-0.06	-0.02	0.07	0.11
	Snow Depth (m)	0.23	0.28	0.33	0.44	0.47	0.50	0.58	0.74	0.94	0.71	0.56	0.53	0.26	0.34
5 South	Ice Thickness (m)	1.88	1.93	2.22	2.60	2.39	2.63	3.38	1.98	1.60	1.60	1.55	1.57	1.68	1.64
	Freeboard (m)	0.13	0.13	0.14	0.09	0.13	0.06	0.38	-0.08	-0.06	-0.04	-0.07	-0.05	0.08	0.08
	Snow Depth (m)	0.20	0.14	0.39	0.44	0.46	0.58	0.27	0.89	0.82	0.70	0.72	0.52	0.32	0.27
6 South	Ice Thickness (m)	1.88	1.81	1.98	2.30	2.52	2.38	3.27	1.61	1.32	1.36	1.39	1.61	1.79	1.88
	Freeboard (m)	0.13	0.11	0.10	0.10	0.10	0.10	0.47	-0.16	-0.13	-0.11	-0.10	-0.02	0.11	0.12
	Snow Depth (m)	0.19	0.18	0.28	0.36	0.40	0.41	0.27	0.68	0.56	0.72	0.62	0.40	0.23	0.18
7 South	Ice Thickness (m)	1.86	1.85	1.78	2.47	2.37	2.31	2.90	1.40	1.29	1.42	1.57	1.67	1.71	1.84
	Freeboard (m)	0.14	0.13	0.09	0.15	0.18	0.16	0.34	-0.09	-0.09	-0.07	-0.01	0.05	0.11	0.14
	Snow Depth (m)	0.16	0.22	0.37	0.38	0.32	0.38	0.24	0.76	0.64	0.41	0.38	0.26	0.23	0.13
8 South	Ice Thickness (m)	1.82	1.80	1.85	2.15	2.43	2.68	3.40	2.25	1.25	1.45	1.56	1.69	1.82	1.87
	Freeboard (m)	0.11	0.11	0.70	0.10	0.13	0.17	0.40	-0.14	-0.12	-0.08	-0.02	0.04	0.13	0.14
	Snow Depth (m)	0.20	0.15	0.33	0.32	0.36	0.67	0.22	0.82	0.75	0.58	0.47	0.34	0.14	0.12
9 South	Ice Thickness (m)	1.89	1.80	1.77	2.16	2.26	2.45	2.50	1.50	1.39	1.45	1.58	1.77	1.82	1.85
	Freeboard (m)	0.13	0.11	0.08	0.11	0.15	0.15	0.35	-0.06	-0.06	-0.08	0.00	0.07	0.12	0.14
	Snow Depth (m)	0.21	0.17	0.31	0.28	0.29	0.43	0.18	0.68	0.62	0.51	0.34	0.29	0.16	0.15
10South	Ice Thickness (m)	1.92	1.92	1.86	2.17	2.27	2.42	2.95	1.49	1.39	1.52	1.64	1.73	1.80	1.86
	Freeboard (m)	0.14	0.18	0.08	0.12	0.14	0.12	0.24	-0.08	-0.07	-0.04	-0.01	0.04	0.10	0.12
	Snow Depth (m)	0.11	0.20	0.29	0.28	0.27	0.51	0.20	0.57	0.53	0.45	0.41	0.32	0.20	0.16

and flexural strength measured at survey line 3 south are presented with the data of Admiralty Inlet in Table 3.1. The shear ridge was composed of unconsolidated ice blocks which formed a narrow ridge along the shear zone across the mouth of Strathcona Sound. It was found that the ridge extended approximately 20m from the crown in the east - west direction before petering out. **Figures 3-3 and 3-4** illustrate the profile of the shear edge at survey lines 3 south and 4 south respectively. In general, the ice was slightly thicker along the west side of the ridge with a sharp increase in thickness observed 4 m from the crown. This is represented by the spikes in the profiles of Figures 3-3 and 3-4 at the 0 m point. The ice cover returned to normal thickness of 1.60 to 1.80 m east of the crown. This was found to be the range of level ice thicknesses. Correspondingly the snow cover was observed to be deepest along the east side of the ridge where the ice cover was not as thick. The average snow depth was 0.45 m with values of up to 0.90 m measured 1 m east of the crown. The ridge sail at survey site 3 south is shown in **Plate 3-10**. The upturned blocks along the crown were approximately 0.50 m high and covered extensively by hard packed snow.

The thickness patterns noted above were also observed for the freeboard values. These were highest at the crown, averaging 0.46 ± 0.17 m and shifting to negative values 1 m east of the axis. Freeboard remained negative at most of the survey sites up to 10 m east of the crown. The average values were -0.09 ± 0.04 m at 1 m from the axis to -0.04 ± 0.3 m at 10 m east of the ridge axis. No negative freeboards were recorded on the west side of the ridge. The data indicates the ridge to be a shear ridge, wherein the east side ice sheet during formation was landfast while the west, seaward side ice sheet was mobile. The west ice sheet moved along the east sheet, creating stress forces and ice failure at the edge. The result was a build-up of grey and grey-white ice blocks along the edge of the east ice sheet.

A representative core was extracted from the ridge at survey site 3 south, 2 m west of the ridge crown. The resulting salinity profile is presented with the other salinity profiles in Appendix B. It was very similar to the profiles obtained at the full sites in Admiralty Inlet. The average salinity value for the core was 4 ppt, 0.8 ppt less than the mean values obtained for the other Admiralty Inlet cores.

The ice temperatures for the ridge were found to be similar to the Strathcona Sound values. The average value was -3.8°C, approximately 1° to 1.5°C higher than the values recorded at the sites in Admiralty Inlet. The flexural strength of the ridge at the survey site 3 south was calculated at 430 kPa, the lowest value calculated for the pre-probe data set for Admiralty Inlet.

FIGURE 3-3

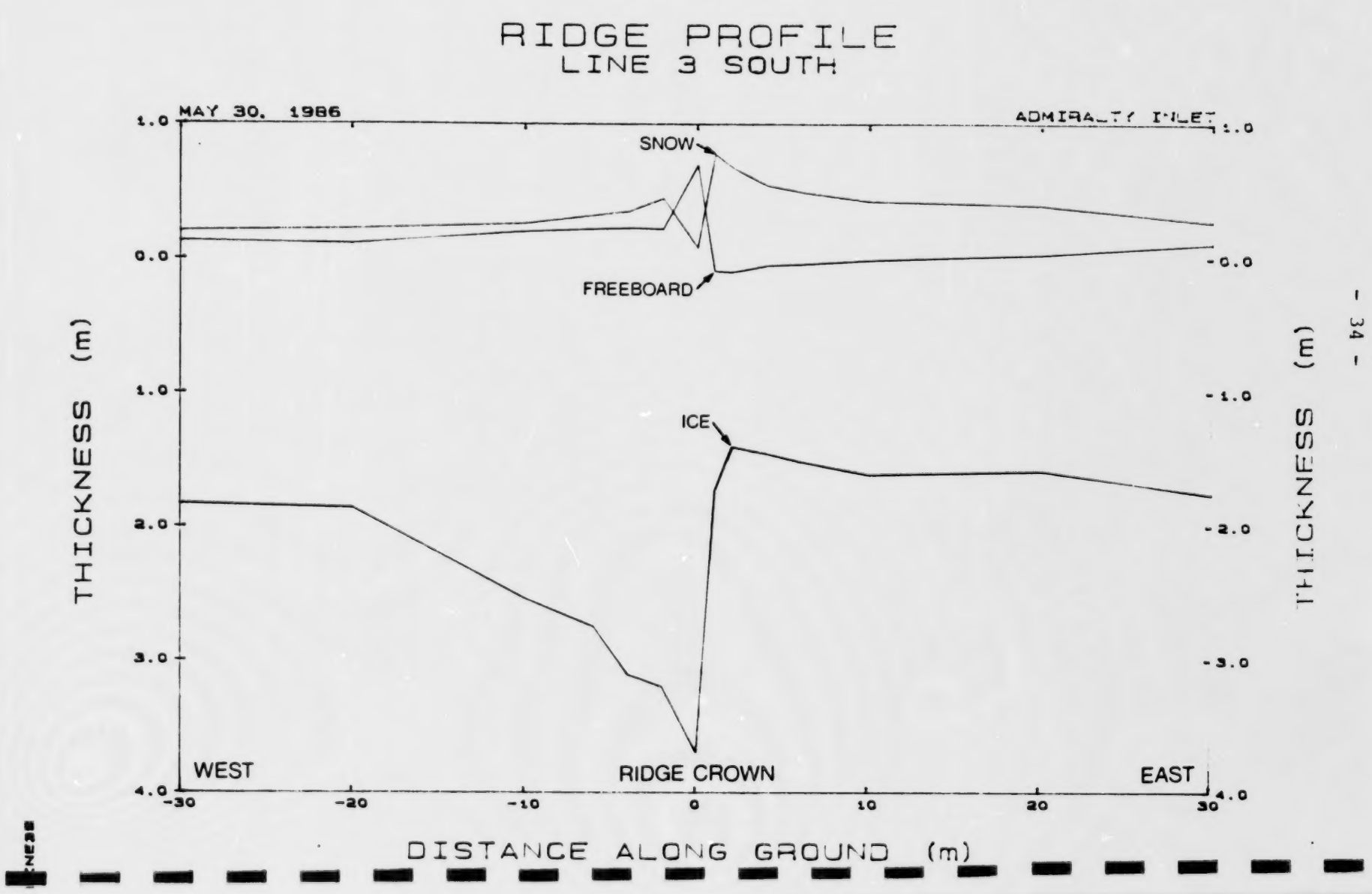

RIDGE PROFILE
LINE 3 SOUTH
MAY 30, 1986
ADMIRALTY INLET
SNOW
FREEBOARD
ICE
WEST
RIDGE CROWN
EAST
THICKNESS (m)
THICKNESS (m)
DISTANCE ALONG GROUND (m)
1.0
0.0
1.0
2.0
3.0
4.0
-30
-20
-10
0
10
20
30

FIGURE 3-4

RIDGE PROFILE
LINE 4 SOUTH

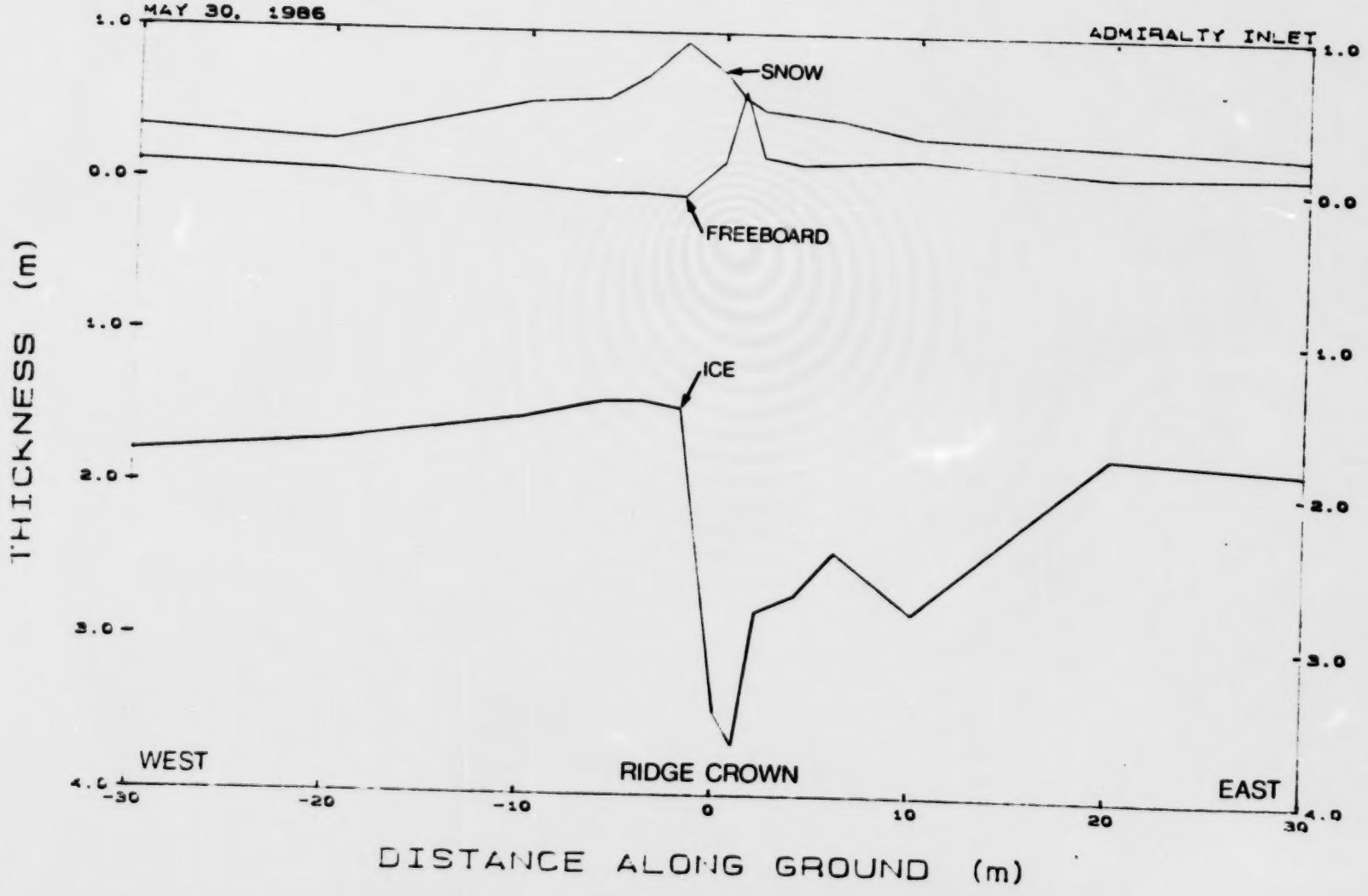


PLATE 3-10

A View of the Shear Ridge Sail at Survey Site 3. Ice thickness at the sail was 3.70m, freeboard was 0.70m and the snow depth was 1.08m.

4.0 ADMIRALTY INLET SHIP TRACK STUDY

4.1 Introduction

The information set presented here represents the data collected under Task 5 - Ship Performance Tests, conducted in Admiralty Inlet during the period June 5th to June 8th. The focus of this task was to study the ship track caused by the new bow configuration and characterize its shape, width and distribution of ice pieces. The track was analysed for the following parameters:

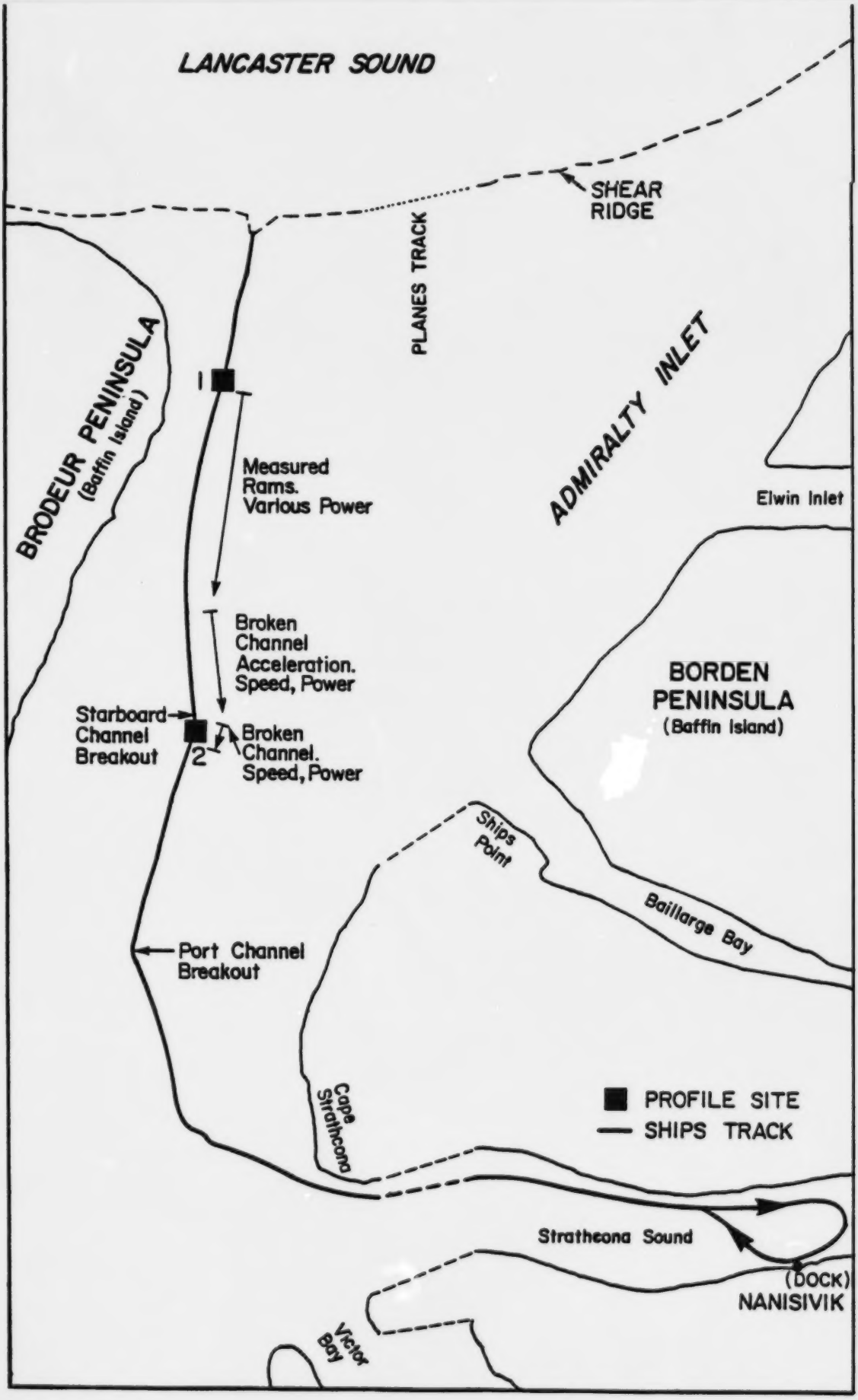
- o track width and cusp spacing
- o ice piece size and distribution
- o percent coverage of track with ice.

In addition 35mm photography was taken of the track as well as a video recording of the ridge ramming tests. The results of the field work are summarized and presented as tables and figures. Statistical analyses were performed on some of the data and the results and conclusions are also presented with this section.

4.2 General Observations on the Ship Track

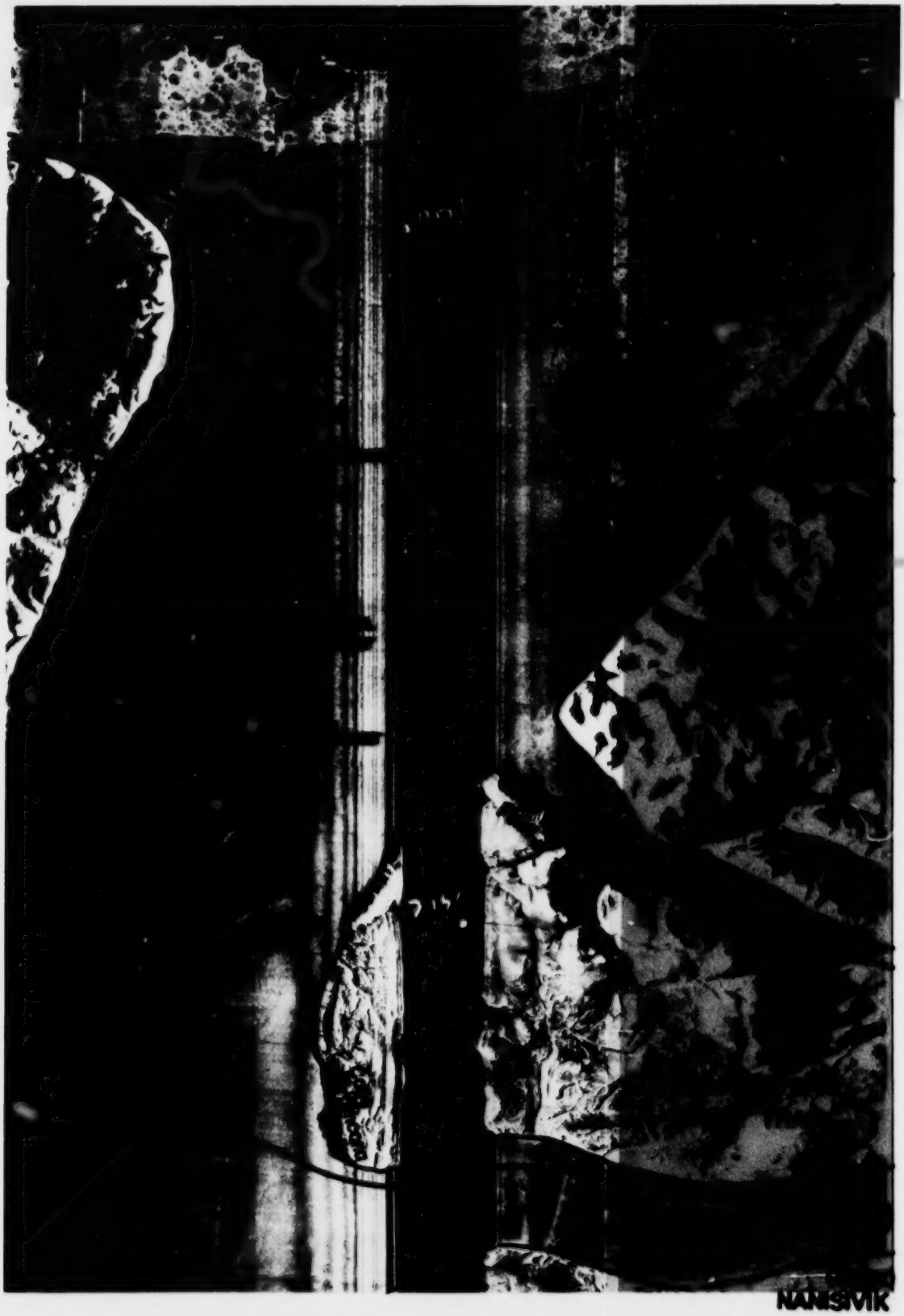
The M.V. Arctic successfully negotiated the proposed ship route into the Nanisivik docksite. The main mode of transit for the vessel was continuous light ramming at 100% power, with the average forward speed of the ship approximately 2-4 knots. The vessel performance tests were conducted by Melville personnel at various points along the track. The vessel performed broken channel speed/power and acceleration tests, as well as a channel breakout test between the survey sites chosen to characterize the ship track. South of the second survey site another channel breakout test and the ridge ramming tests were performed. Measured rams were recorded throughout the length of the transit. **Figure 4-1** is a June 24th SLAR Image of Admiralty Inlet with an overlay showing the locations of the survey sites in relation to the ship transit modes for the in-bound transit.

The ice along the ship track was all first year, consolidated level ice having a fairly uniform thickness of 1.80m. **Figure 4-2** shows a profile of the ice thickness along the track obtained from selecting the closest ice test sites. **Table 4.1** lists the ice sites and their measured ice thickness. The vessel crossed the shear ridge at the optimum point marked by the field team with no difficulty. In fact the ship did not come to a stop until a full ship's length past the ridge sail. The ridge position is indicated on the profile in Figure 4-2 by the sharp increase in ice thickness values.



SHIP TRANSIT MODE ALONG SHIP TRACK
ADMIRALTY INLET JUNE 4-6, 1986

LANCASTER SOUND



SHIP TRANSIT MODE ALONG SHIP TRACK
ADMIRALTY INLET JUNE 4-6, 1986

FIGURE 4-2

ICE THICKNESS ALONG SHIP TRACK
ADMIRALTY INLET TO NANISIVIK DOCK

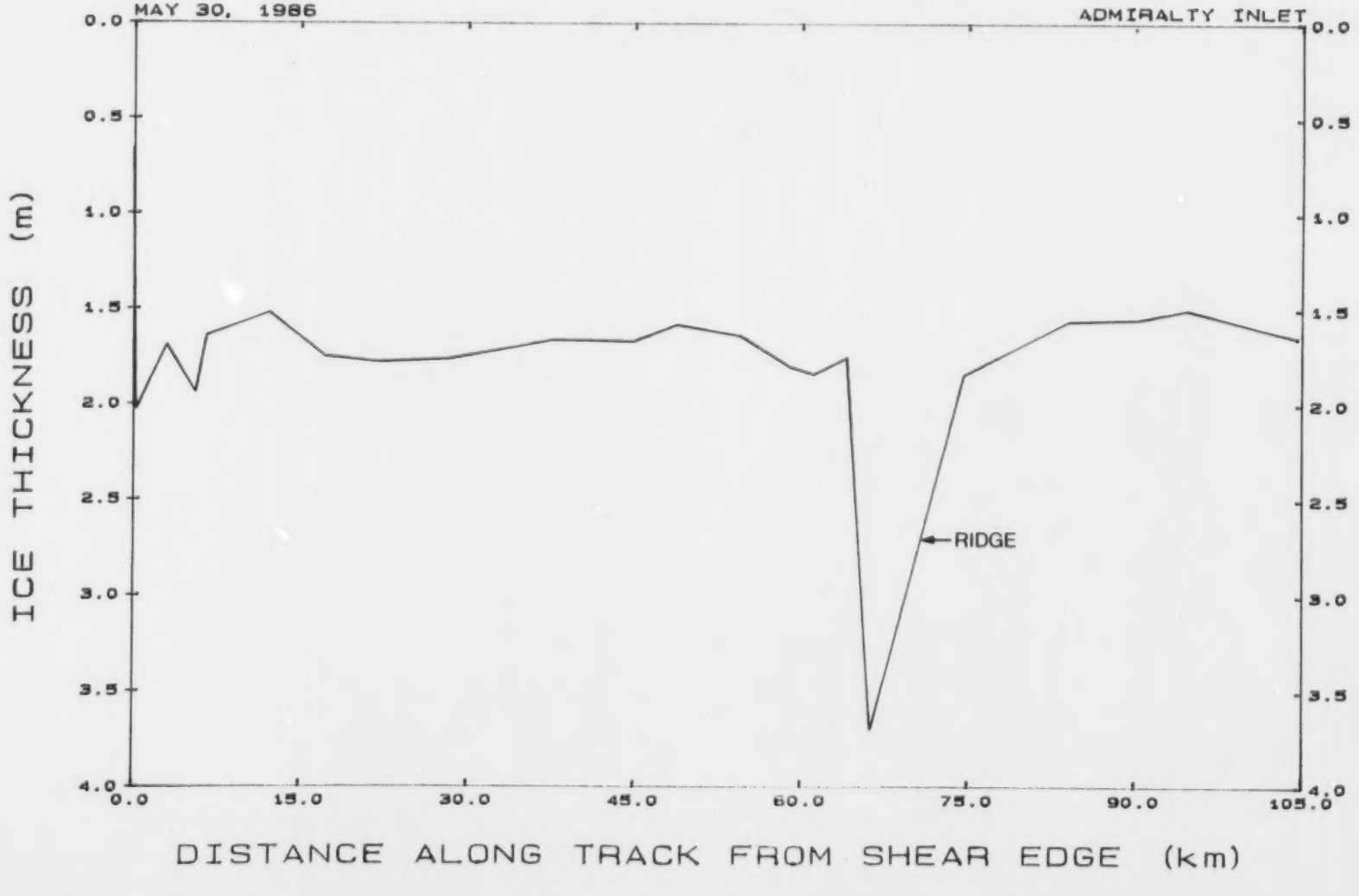


TABLE 4.1

ICE THICKNESS ALONG SHIP ROUTE IN ADMIRALTY INLET AND STRATHCONA SOUND (TAKEN FROM CLOSEST STATION)

ICE THICKNESS (m)	STATION*	DISTANCE ALONG (km) TRACK FROM SHEAR EDGE (Approx.)
0.66	H31	0.0 (north side of shear edge)
2.03	H1-3($\bar{x}$)	0.3 (south side of shear edge)
1.69	H21	3.0
1.94	H4-9($\bar{x}$)	5.6
1.64	H10	6.6
1.52	H11	12.2
1.75	1	17.2
1.78	H25	22.1
1.76	2	28.3
1.66	5	37.7
1.67	H52-53($\bar{x}$)	44.9
1.58	H27	48.8
1.64	8	54.5
1.72	H22	56.7
1.80	H23	58.9
1.84	H24	61.1
1.75	9	64.1
3.70	Ridge(35)	66.3
1.84	H32-34($\bar{x}$)	74.6
1.56	H37-38($\bar{x}$)	84.0
1.55	51	90.3
1.50	H30	94.7
1.65	H39-50($\bar{x}$)	104.6

* Data taken from closest ice station.

From aerial observations of the track created by the M.V. Arctic it could be determined that the track had distinct ice distribution characteristics. Three types of ice concentrations were distinguished; open water, medium packed ice and dense packed ice. These distributions were found to be dependent upon the ship operating mode. The open water patches were caused when the ship moved astern and the medium and dense packed ice concentrations were the result of the varying interaction of the ship propulsion system with the ice pieces. This is discussed in more detail in Section 4.3.2. **Plates 4-1 to 4-3** illustrate these features.

Plates 4-1 and 4-2 are aerial photos of the track at site 1 and site 2 respectively. Plate 4-1 is a south view of survey site 1 at the start of the profile length. The track consisted of close pack and several large 15 X 10m floes can be seen in the matrix in the photo. Just to the south of the large floes is an area of medium packed ice. Plate 4-2 is a north view of site 2 after the second ship passage. The track consisted of medium packed ice and has a high percentage of brash in its matrix.

Plate 4-3 shows the M.V. Arctic moving astern, down the track after a ram. The backwash motion created a mainly open water track with a few pieces of brash and small floes floating in the matrix.

4.3 Data Presentation and Analysis

Data Collection

The data sets were collected from two profile sites established along the ship track as shown in Figure 4-1. Site 1 was located in level ice approximately 12km below the entry point of the M.V. Arctic into Admiralty Inlet. Site 2 was situated just south of lead 2. The length of each profile site was 200m and data measurements were taken at every 10m point. The track was photographed at various perspectives at both ice level and from approximately 100 feet in the air by helicopter.

Each site represents a sample of the track under different transit conditions. Site 1 represents a single transit and site 2 simulates an in-bound and out-bound passage by the same vessel. Due to time complications the field team was unable to wait until the actual out-bound passage of the M.V. Arctic to obtain the required track conditions. A simulated out-bound pass was made by the vessel reversing up the track and then proceeding back down the track through the profile site a second time. The track was analysed after the first run and then again after the second run. The track transit

PLATE 4-1: Aerial Photo of the Ship Track from an Altitude of 75 feet. The photo is a south view of survey site 1. The garbage bag marks the start of the survey profile.

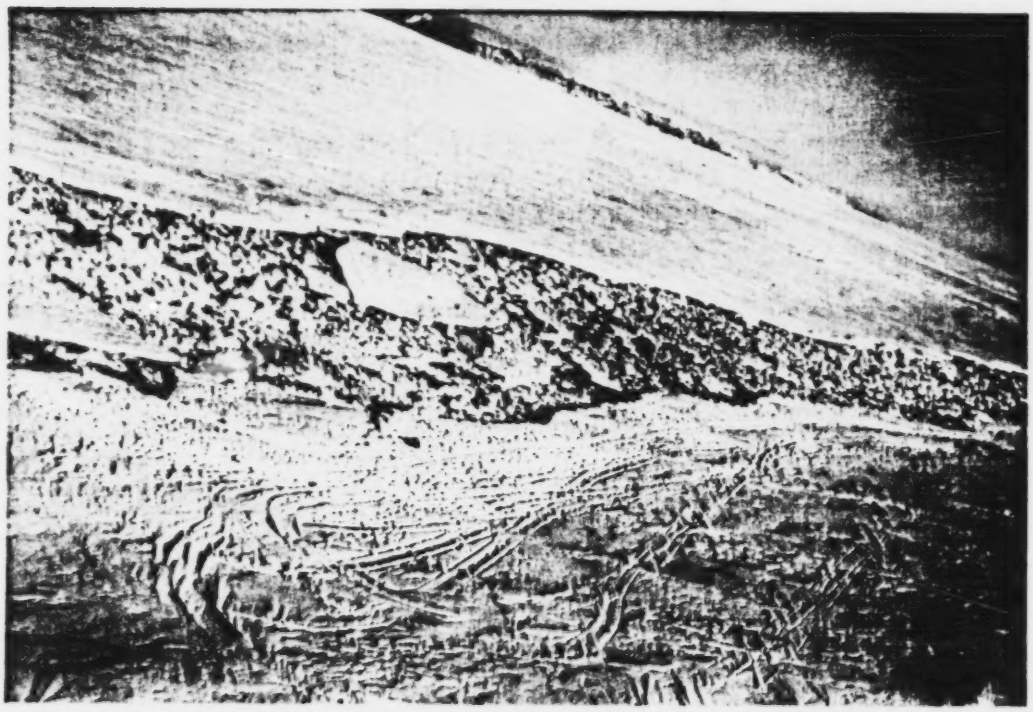


PLATE 4-2: Aerial Photo of the Ship Track from an Altitude of 100 feet. The photo is a north view of survey site 2 after the second passage of the ship.

PLATE 4-3

The M.V. Arctic Moving Astern up the Track South of Site 2.

is summarized below.

track characteristics	site 1	site 2
inbound	run 1	run 1
outbound	---	run 2

The results of the data collected by the field team are presented in the form of summary tables and figures. Each track parameter is discussed in a separate sub-section. The video recording of the ship ramming the ridge is presented under separate cover, but is discussed in this section.

The parameter of ice thickness along the track was sampled at a few locations along the track at distances of 0, 2 and 5 m back from the edge. The thickness was measured mainly to ascertain whether or not the ice pieces within the track were forced under the track edge. It was found that the ice pieces were forced under the track immediately adjacent to the track edge at distances up to 2 m from the edge, but that within 5 m from the edge the ice thicknesses were characteristic of the thickness values measured at the ice sites. During drilling of the holes, the auger would initially drill through the ice cover and then slip and hit a second underlying piece of ice.

4.3.1 Track Width

The track width was measured at every 10 m point along the profile site. A field survey tape was stretched from the starboard edge of the track to the port side and the distance recorded. The edge of the track was considered to be at the intersection where the ice had cleaved off from the consolidated cover. Cracks that did not propagate through the ice cover were not considered to represent the track edge. However, their formations were recorded because of their influence with the track cusping pattern.

Table 4.2 is a summary of the track widths recorded for both profile sites. At site 1, an additional 800 m of the track was measured for the Indian and Northern Affairs program and the information, because of its relevance to this data base is included with the profile 1 data. The mean track widths represent the average of the sum of the widths measured at each 10 m point. The extended 800m profile values were added to the 200 m profile values at site 1.

It was found that the mean track widths of both sites were similar and that a negligible difference in mean width was observed between runs 1 and 2 at profile site 2. Profile

TABLE 4.2

SUMMARY TABLE OF MEAN TRACK WIDTH AT PROFILE SITES 1 AND 2, ADMIRALTY INLET

PROFILE SITE NO.*	DATE	MEAN TRACK WIDTH (m)	STANDARD DEVIATION	SAMPLE SIZE
1	June 5	35.2	4.9	21
1 (extended 1 km study)	June 8	30.9	4.8	101
2 (first run)	June 6	28.8	3.0	21
2 (second run)	June 6	28.8	2.9	21

* Length of each profile was 200 m unless otherwise indicated.

site 1 had a mean track width of 35.2 m for the 200 m length profile and an average width of 30.9 m for the 1 km survey. Both profiles for site 2 had a mean track width of 28.8 m. The difference in mean width between the 200 m profile 1 survey and site 2 surveys was 6.4 m and between the extended profile 1 survey and site 2 survey, only 2.1 m. The difference in mean width between the 200 m and 1 km survey at site 1 could possibly reflect a difference in measuring techniques by the field personnel. All the surveys except the 1 km survey were done by the same personnel. The numbers represent a relatively small numerical difference, but the difference is attributed cusping patterns. These were quite variable with open and closed cusps occurring. The track width was always measured from the level ice remaining adjacent to the broken track, eveb if there was a crack defining a closed cusp pattern.

Figures 4-3 and 4-4 represent, respectively, the track width profiles for site 1 (200 m survey) and site 2, run 1. If the profiles are overlaid it can be seen that they have a similar trend, with the peaks and dips, indicating the cusping pattern, located at the same points along the track in each profile. The site 1 profile was observed to have a more jagged track edge with a higher width standard deviation of 4.9m. The site 2 track width profile was smoother and had a standard width deviation of 3 m.

According to the ship's log, the transit mode of the vessel through site 1 and site 2, run 1 was continuous ramming at 100% power with a speed of 2 knots. The second run at site 2 was broken channel acceleration with full power at a speed of 7 knots. **Figure 4-5** presents the profile for run 2. These different transit modes seemed to have no effect on the ship track width as the profile for run 2 was the same as for run 1. It is possible that the larger width values recorded at site 1 reflect the influence of the dynamics of the vessel reversing after ramming. Within the vicinity of site 1, the vessel performed standard rams wherein the ship, after impact would slow down to a speed of about 1.0 knots and then stop. It was reported that this method of ramming decreased the average speed of advance and increased the number of rams. A different ram type was subsequently employed, labelled a transition zone ram. In the transition zone ram the vessel continued at approximately 1.0 knot for a considerable time lapse after the initial deceleration. It was found that the forward advance of the transition zone was usually greater than that of a standard ram (Melville Shipping Ltd., 1986).

The interaction of the ice cover properties with the dynamics of the propulsion system as it continuously reversed and rammed in a different mode at site 1 might have affected the ice - propeller interaction slightly differently than it did

FIGURE 4-3

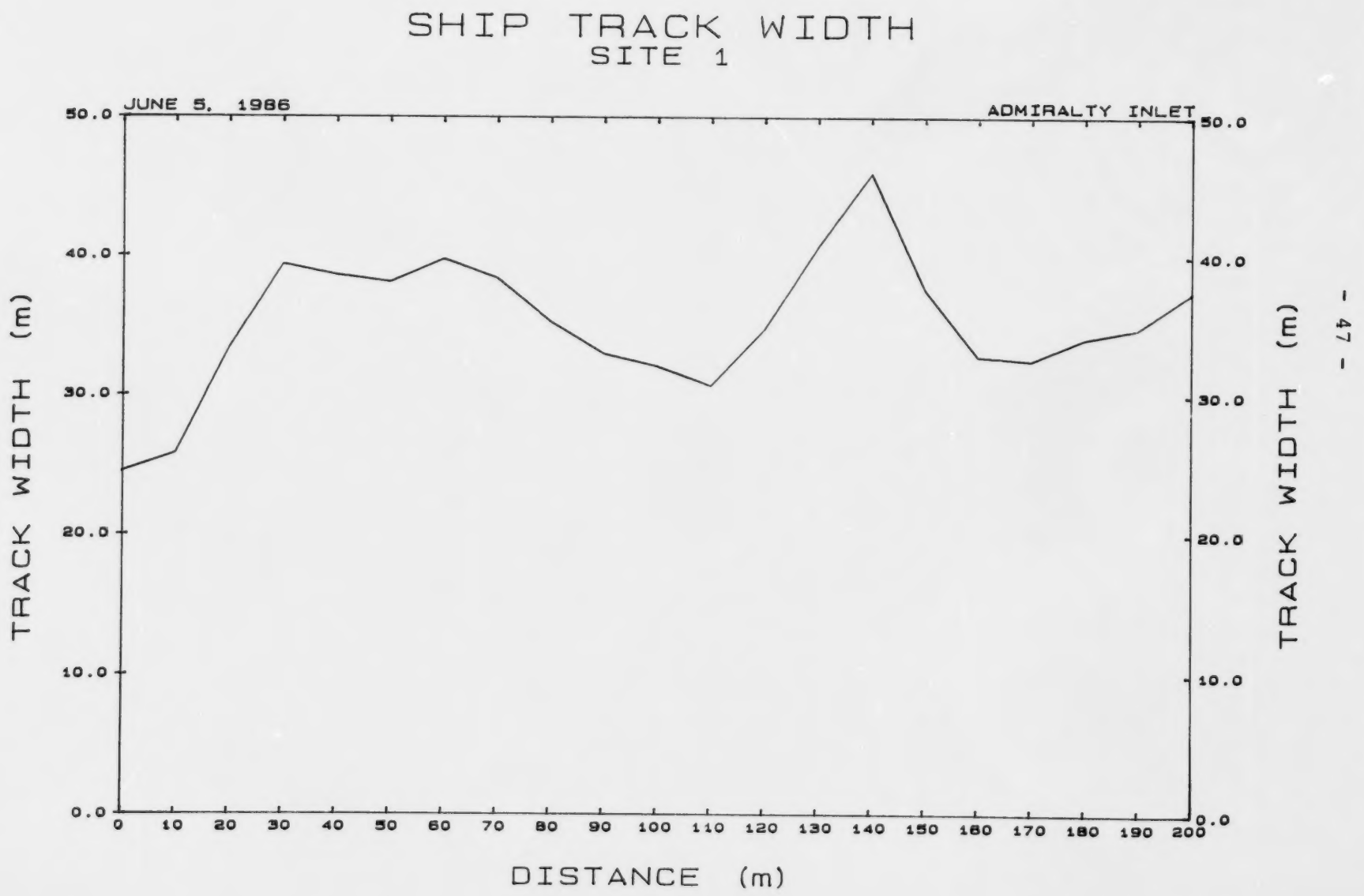
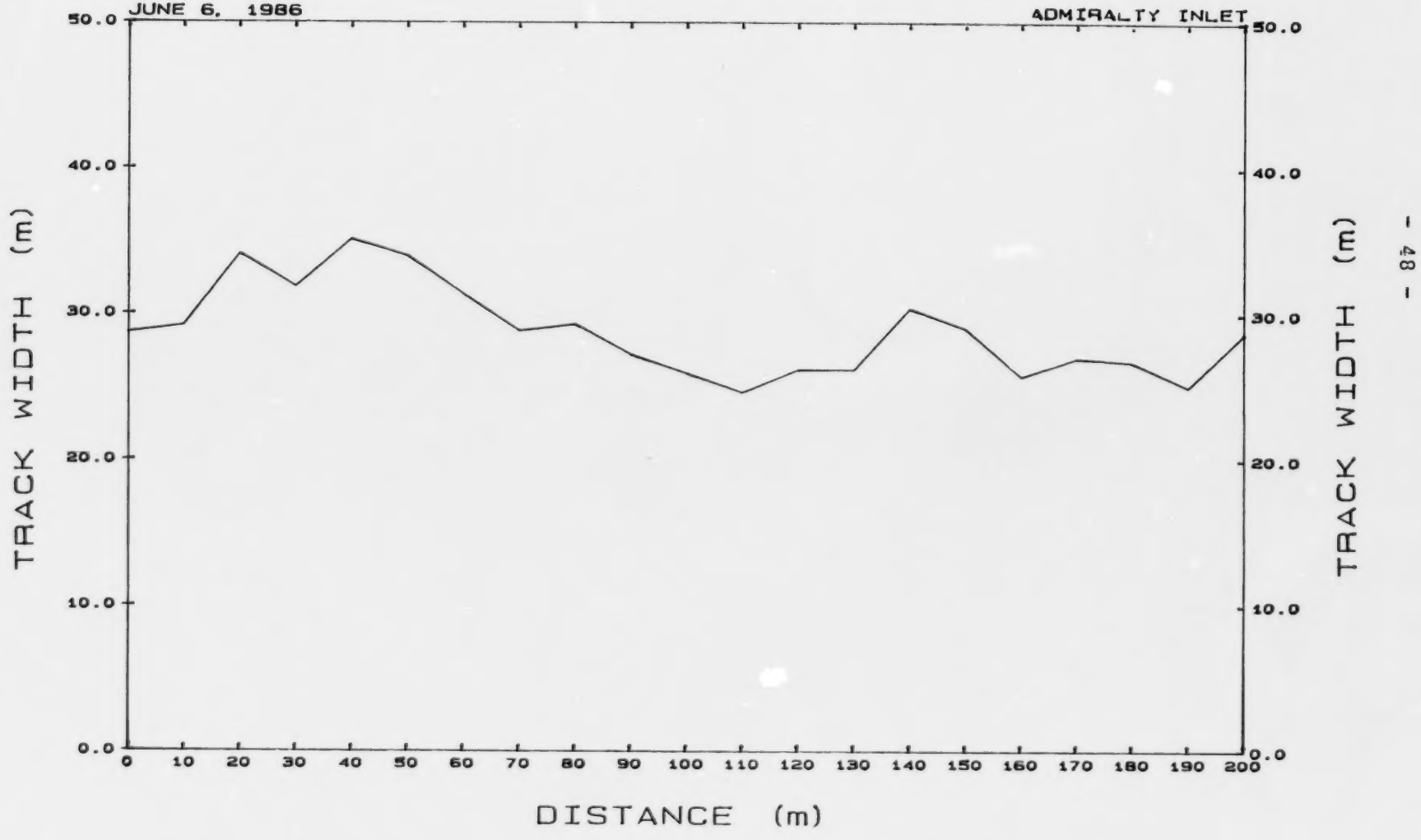

SHIP TRACK WIDTH
SITE 1
JUNE 5, 1986
ADMIRALTY INLET
TRACK WIDTH (m)
TRACK WIDTH (m)
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
DISTANCE (m)
PS1200M

FIGURE 4-4

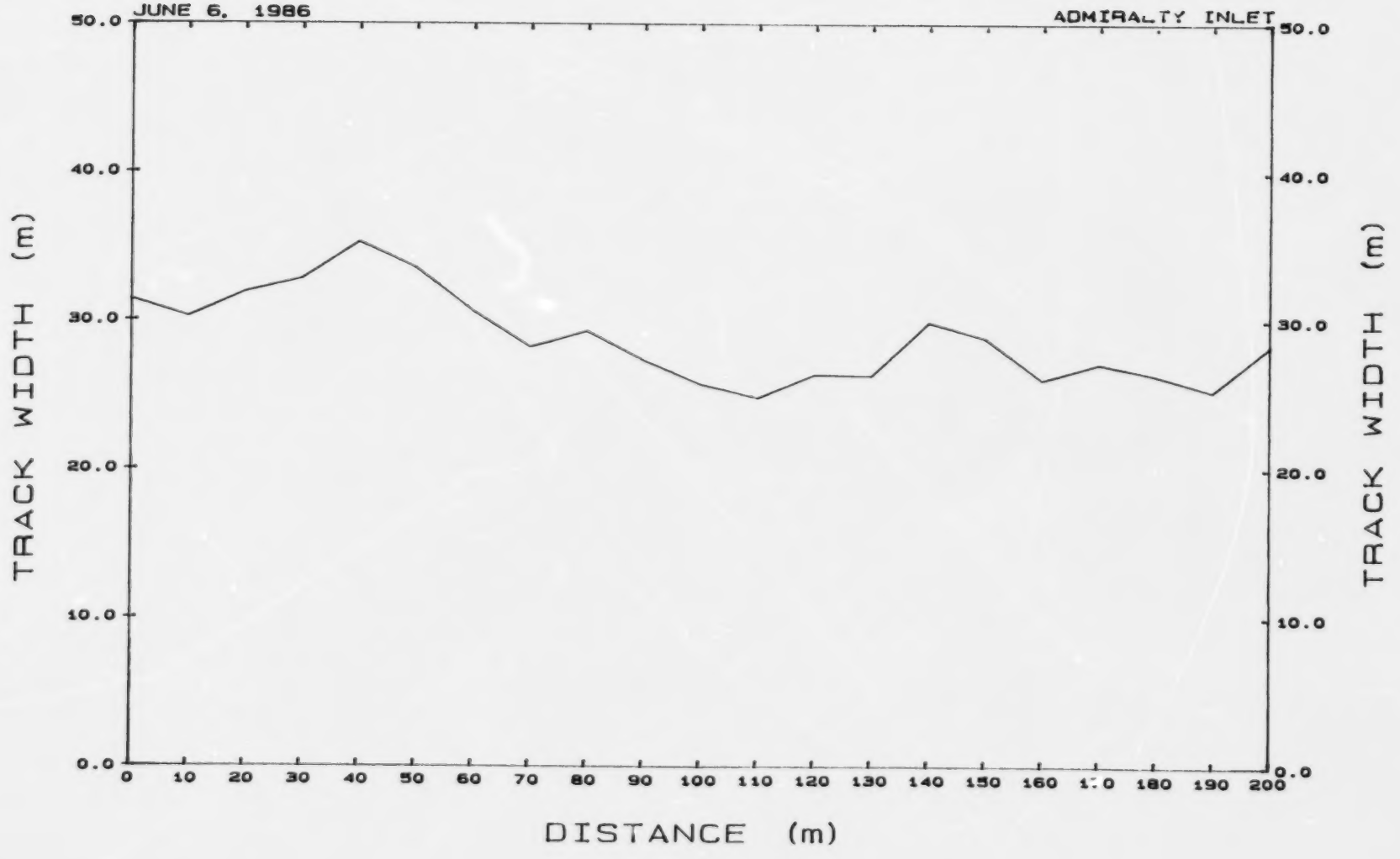
SHIP TRACK WIDTH
SITE 2. RUN 1



P92A1

FIGURE 4-5

SHIP TRACK WIDTH
SITE 2, RUN 2



at site 2. It is highly likely that the parameter of ice thickness which, although fairly consistent, did vary along the track, also influenced the ice breaking resistance. **Figure 4-6** presents the profile of the track width for the extended survey at site 1. From the profile it can be observed that a high degree of cusping occurred along the track, particularly between the 0 to 650 m section. Again, this is considered to represent the dynamics of the ship - ice interaction as it continuously rammed and reversed down the track.

4.3.2 Ice Piece Size Distribution and Percent Coverage of the Track

The field team chose six size categories to define ice piece size and permit the analysis of size distribution. The six categories were:

- o open water
- o brash
- o 2 m X 1 m
- o 4 m X 2 m
- o 7 m X 4 m
- o 15 m X 10 m.

These floe size categories were chosen after a detailed visual analysis of the track. It was observed that the ice floes most closely approximated these sizes.

Measurements of ice piece size and distribution were made at every 10 m distance along both profile sites and for each run at site 2. Two field team members stood on opposite sides of the track edge and each visually estimated the percent cover of the track by the six ice piece size categories. The estimates were then verbally compared and agreed upon and the numbers entered in the field books. This process was repeated for each 10 m section until the entire 200 m had been covered. The results are presented as a series of summary tables and histograms. In addition, statistical analyses of the percent coverage and ice piece distribution were completed.

Plates 4-4 to 4-7 highlight the ice conditions in the track at the survey sites. All 4 photos were taken at site 2 after run 2. The photos illustrate the extent to which the M.V.Arctic churned up the ice. Plates 4-4 and 4-5 were taken at a crossing site along the survey profile. A mixture of small 2 X 1 m floes and larger 7 X 4 m floes are visible in both photos. It was found that quite a few of the small floes were tossed up at 45 degree angles onto the larger floes. This is illustrated in Plate 4-5.

FIGURE 4-6

SHIP TRACK WIDTH
PROFILE SITE 1

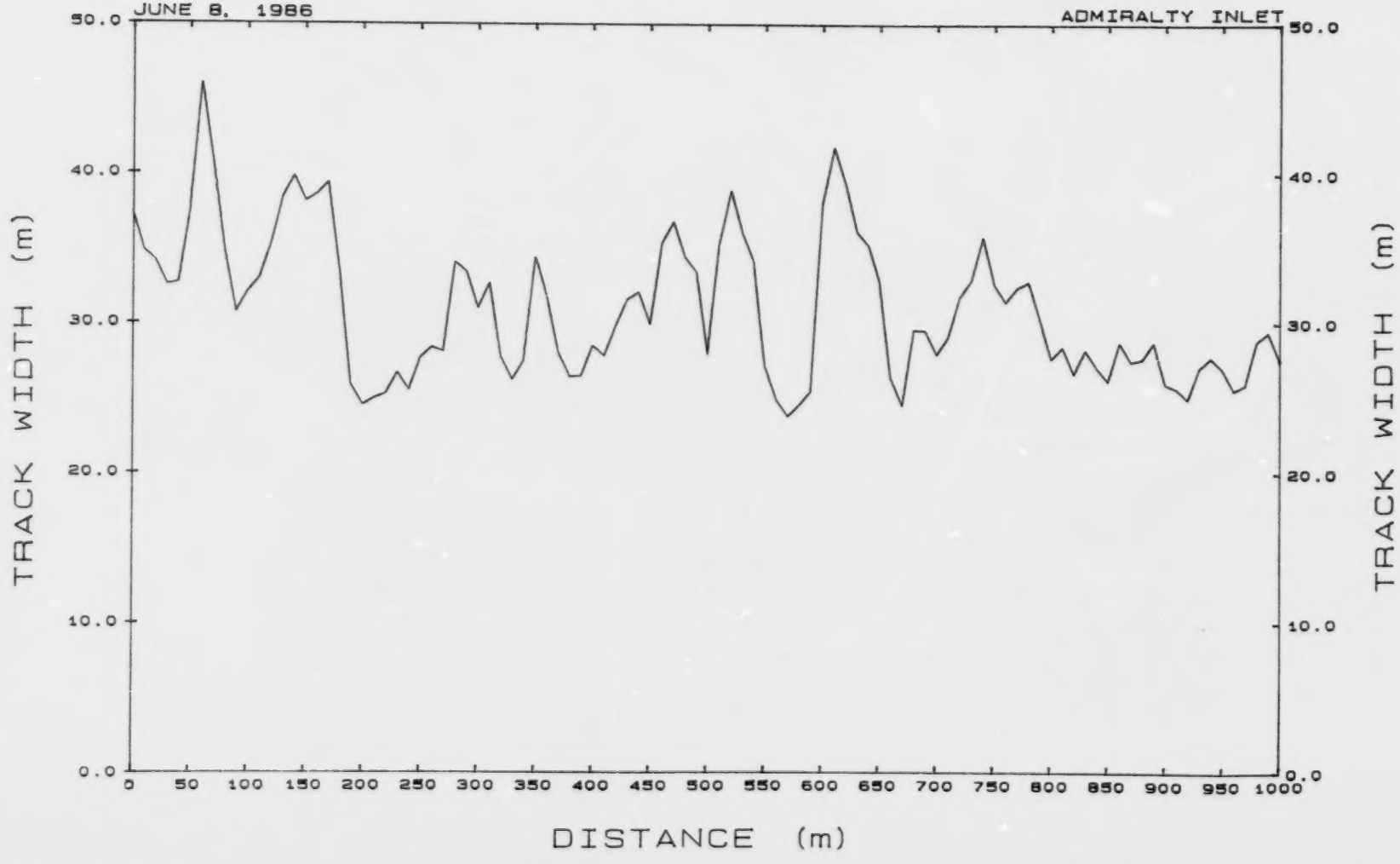


PLATE 4-4: Ice Conditions in the Track at Site 2, After the Second Ship Passage. The site was determined to be a crossing site. The view is from the port side looking to starboard.

PLATE 4-5: Crossing Point at Site 2, After the Second Ship Passage. It was found that quite a few small floes were tossed on top of the larger floes as shown in the photo.

PLATE 4-6: View South Down the Track at the Crossing Point in Plate 4-4. Small floes can be seen on top of the larger floes.

PLATE 4-7: View North Along the Survey Profile at Site 2 After the Second Ship Passage. The track at this location had a high percentage of brash, visible in the foreground of the photo.

Plates 4-6 and 4-7 are photos of the track taken from the perspective of looking along its length. Plate 4-6 is a south view down the centre of the track taken at the same location shown in Plate 4-4. The M.V. Arctic is visible further south down the track. The track consisted of dense pack ice having a high percentage of brash and small floes. Plate 4-7 is a north view of the track along the starboard edge. The cusping pattern is clearly shown in the photo. The track at this location (0 m point in the profile survey) consisted of medium pack ice with a high percentage of brash. Upturned blocks are visible in the centre of the track.

The results of the ice piece distribution are summarized in **Tables 4.3 and 4.4.** The percent coverage by each of the size categories for every 10 m survey section were added together and the mean value calculated. The values presented in the tables present the mean percent coverage of the total 200 m track profile by the six size categories. Table 4.3 compares profile site 1 with profile site 2, run 1, while Table 4.4 compares run 1 with run 2 at profile site 2.

From Table 4.3 it is apparent that there is a major difference in the percent coverage by ice size between the 2 profile sites for the size categories brash and 7 m X 4 m. The differences calculated for the other ice sizes are negligible and within the experimental error of the field team's ability to visually estimate piece size distribution.

The total coverage of the track at site 1 by brash was 51.25% and at site 2, run 1 it was 31.75%. For the size category 7 m X 4 m, the percent coverage was 9.0% at site 1 and 24.0% at site 2. The higher percentage of smaller floe sizes in the track at site 1 could indicate the influence of a standard ram mode as opposed to the transition zone ram. In the standard ram mode, the vessel reverses more frequently than it does in a transition ram and it is possible that this operating mode created the higher percentage of brash observed at site 1. This is a hypothesis only and would have required more detailed field work and a more precise knowledge of the ship operating mode to be able to compare the influence of a standard ram versus a transition ram on the ice piece distribution.

In Table 4.4 the same differences in percent coverage by size was observed for the size categories brash and 7 m X 4 m. In run 1 brash accounted for 31.75% of the ice coverage and in run 2 60.25% of the ice pieces were brash. Correspondingly, 24.0% of the ice was composed of 7 m X 4 m floes in run 1 but accounted for 5.6% of the floe sizes in run 2. There were more smaller floe pieces in the second run than there were for the first run, clearly indicating that as the vessel reversed up the track after run 1, the interaction of the

TABLE 4.3

ICE DISTRIBUTION ANALYSIS, PROFILE SITES 1 AND 2
JUNE 5-6, 1986

ICE PIECE SIZE CATEGORIES	SITE 1, MEAN % COVERAGE OF TOTAL	SITE 2, FIRST RUN' MEAN % COVERAGE OF TOTAL	DIFFERENCE
Open Water	4.5	4.0	-0.5
Brash	51.25	31.75	-19.5
2 X 1 m	16.25	16.75	+0.5
4 X 2 m	13.0	14.5	+1.5
7 X 4 m	9.0	24.0	+15.0
15 X 10 m	6.0	9.0	+3.0

TABLE 4.4
ICE DISTRIBUTION ANALYSIS, PROFILE SITE 2
JUNE 6, 1986

ICE PIECE SIZE CATEGORIES	FIRST RUN, MEAN % COVERAGE OF TOTAL*	SECOND RUN, MEAN % COVERAGE OF TOTAL	DIFFERENCE
Open Water	4.0	1.5	-2.5
Brash	31.75	60.25	+28.5
2 X 1 m	16.75	17.25	+0.5
4 X 2 m	14.5	13.65	-0.85
7 X 4 m	24.0	5.6	-18.4
15 X 10 m	9.0	1.75	-7.25

* % coverage of total 200 m survey profile

propellor with the ice floes broke up many of the larger ice floes into smaller ones and reduced many of the smaller floes into brash.

To further illustrate the differences in ice piece distribution at each site and between each run at site 2, **Figure 4-7 and 4-8** are stacked histograms comparing the ice size distribution between, respectively, site 1 and site 2, run 1 and between site 2, run 1 and 2. The histograms clearly show the higher amounts of brash in the track at site 1 and at site 2, run 2.

The histograms also indicate the small percentage of open water observed in the track at both sites. For site 1, a total of 4.5% of open water was observed while at site 2, run 1 a similar value of 4.0% was recorded. After the second run at site 2, the area of open water decreased to 1.5% reflecting the higher level of interaction of the vessel propulsion system with the ice in the track.

It is worthwhile to point out that the 2 profile sites represent sites within medium to close pack sections of the track. There were three distinct patterns of ice distribution observed for the track as a whole; including open water, medium pack and close pack ice as mentioned previously in Section 4.2. This cycle is clearly shown in Plates 4-1 to 4-3 accompanying the discussion. The cyclic pattern was related to the motions of the ship. The sections of track consisting of dense pack correspond to the end of the reverse cycle of the ship prior to initiating a new ramming sequence. When the ship moved forward again, the propellor backwash cleared most remaining ice pieces against the already densely packed ice, leaving a section of open water. Medium pack sections resulted from breaking virgin ice where the ship had to back in when initiating another ram sequence. The length of each section varied, but seemed to exceed or equal the 200 m profile length chosen by the field team for the track analysis. This approximately equals one ship length as well as average level ice penetration during ramming.

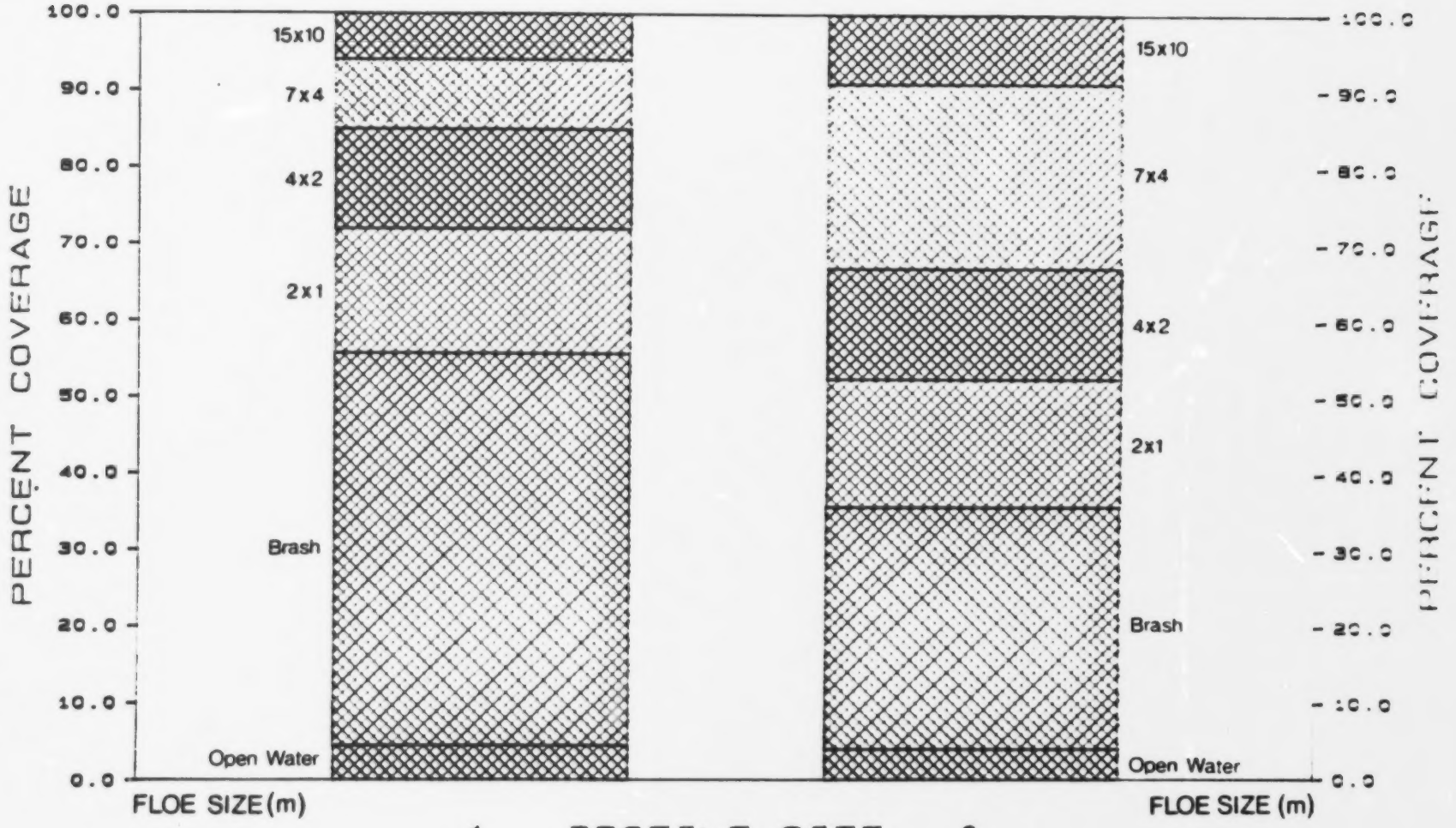
Statistical Analyses

In order to ascertain the reliability of the values of the percent total coverage of the track by the ice piece sizes calculated for Tables 4.3 and 4.4, 2 types of statistical analyses were undertaken. The tests performed on the data were the student T-distribution confidence means test and the null hypothesis testing for small sample sets. The tests assume that the samples were from a population with a normal distribution.

To test the reliability of the ice piece size distribution so as to determine the confidence of the calculated means being

FIGURE 4-7

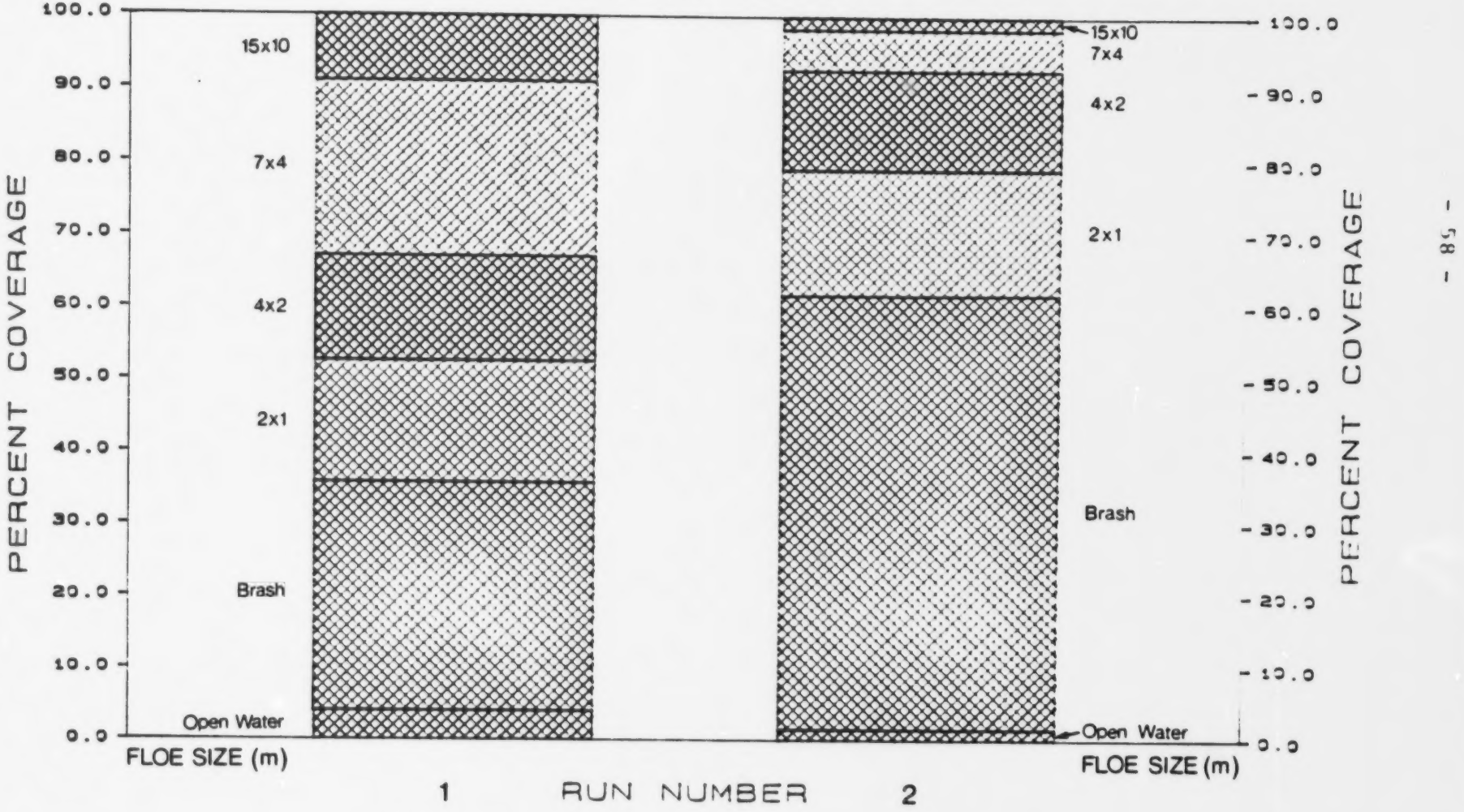
ICE PIECE DISTRIBUTION IN TRACK
PROFILE SITES 1 AND 2
JUNE, 1986



1 PROFILE SITE 2

FIGURE 4-8

ICE PIECE DISTRIBUTION IN TRACK
PROFILE SITE 2
JUNE 6, 1986



within the true mean, the estimation of means test with a confidence level of 90% was applied to the data. The desire was to be able to assert with a probability of 90% that the percent coverage of the track by the six size categories at both sites 1 and 2 were reliable numbers that closely approximated the true mean and could therefore be expected to consistently show up in the track. **Tables 4.5 to 4.8** summarize the results of the analyses.

The basis for the test is the small sample confidence interval

$$\bar{x} - t\alpha/_2\frac{s}{\sqrt{n}} < \mu < \bar{x} + t\alpha/_2\frac{s}{\sqrt{n}}$$

where $t\alpha/_2$= the confidence limit

$\bar{x}$ = sample mean

s = sample standard deviation

n = sample size

μ = true mean

(Freund, 1973).

The confidence interval chosen for the testing was the integer 3. If it was found that the calculated mean did not fall within this interval of the true mean, the calculated mean was considered unreliable and therefore not consistent with the floe sizes expected to be found in the track.

The results of the analysis found that the percent coverage of the track by open water for all four cases were reliable means and could be consistently expected to be found in the track. This was also found to be true for the floe sizes 7 X 4 m and 15 X 10 m at low percent coverage values. However for brash the values were not reliable for any of the four scenarios and for the 4 X 2m floe sizes the results of the analysis were inconsistent. The data seemed to indicate that the floe sizes observed in the track at both sites were, on the whole, unreliable at a confidence level of 90% and therefore could not be considered consistent of the floe sizes expected to be found in the track. It was decided that further analysis was required before any conclusions could be established on the track characteristics.

The statistical analysis using the student T-distribution concerning the significance of the difference between two means was used to quantify the difference in ice piece distribution between the 2 profile sites and between run 1 and run 2 at site 2. To use the test it was again assumed

TABLE 4.5

STUDENT-T DISTRIBUTION
PROFILE SITE 1 - JUNE 05

ICE PIECE SIZE	MEAN % TOTAL COVER OF TRACK ($\bar{x}$)	SAMPLE STANDARD DEVIATION	RELIABILITY OF $\bar{x}$ AT 90% CONFIDENCE INTERVAL*
Open Water	4.5	4.56	Reliable
Brash	51.25	20.58	Unreliable
2 X 1 m	16.25	11.91	Unreliable
4 X 2 m	13.0	11.85	Unreliable
7 X 4 m	9.0	2.08	Reliable
15 X 10 m	6.0	15.0	Unreliable

* $\bar{x}$ considered reliable if confidence interval less than 3

TABLE 4.6
STUDENT-T DISTRIBUTION
PROFILE SITE 2 - JUNE 06 RUN 1

ICE PIECE SIZE	MEAN % TOTAL COVER OF TRACK ($\bar{x}$)	SAMPLE STANDARD DEVIATION	RELIABILITY OF $\bar{x}$ AT 90% CONFIDENCE INTERVAL*
Open Water	4.0	4.17	Reliable
Brash	31.75	9.50	Unreliable
2 X 1 m	16.75	5.45	Reliable
4 X 2 m	14.50	6.47	Reliable
7 X 4 m	24.0	8.68	Unreliable
15 X 10 m	9.0	9.68	Unreliable

* $\bar{x}$ considered reliable if confidence interval less than 3

TABLE 4.7

STUDENT-T DISTRIBUTION
PROFILE SITE 2 - JUNE 06 RUN 2

ICE PIECE SIZE	MEAN % TOTAL COVER OF TRACK ($\bar{x}$)	SAMPLE STANDARD DEVIATION	RELIABILITY OF $\bar{x}$ AT 90% CONFIDENCE INTERVAL*
Open Water	1.5	3.28	Reliable
Brash	60.25	11.30	Unreliable
2 X 1 m	17.25	8.66	Unreliable
4 X 2 m	13.65	7.12	Reliable
7 X 4 m	5.6	7.53	Reliable
15 X 10 m	1.75	4.38	Reliable

* $\bar{x}$ considered reliable if confidence interval less than 3

TABLE 4.8
STUDENT-T DISTRIBUTION
PROFILE SITE 1 & 2 COMBINED, JUNE

ICE PIECE SIZE	MEAN % TOTAL COVER OF TRACK ($\bar{x}$)	SAMPLE STANDARD DEVIATION	RELIABILITY OF $\bar{x}$ AT 90% CONFIDENCE INTERVAL*
Open Water	4.25	4.32	Reliable
Brash	41.50	18.65	Unreliable
2 X 1 m	16.50	9.14	Reliable
4 X 2 m	13.75	9.46	Reliable
7 X 4 m	16.50	11.99	Unreliable
15 X 10 m	7.50	12.56	Unreliable

* $\bar{x}$ considered reliable if confidence interval less than 3

that the samples came from populations which can be approximated closely with normal distributions and have equal variances. The basis of this test is the null hypothesis

$\mu 1 = \mu 2$ on the statistic.

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{\Sigma(x_1 - \bar{x}_1)^2 + \Sigma(x_2 - \bar{x}_2)^2}{n_1 + n_2 - 2} \times \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

where

$\Sigma(x_1 - \bar{x}_1)$ = sum of the squared deviations for the mean for the first sample

$n_1 + n_2 - 2$ = number of degrees of freedom (Freund, 1973).

Two cases were studied; case one wherein the null hypothesis stated that no difference in the means of ice piece distribution between profile sites 1 and 2 (run 1) existed and case two which stated that no difference existed in the means of ice piece distributions between runs 1 and 2 at site 2. The results of the tests are presented in **Tables 4.9 and 4.10.**

It was found that no consistent results could be observed for both case studies. In case 1 the variance in ice piece distribution were equal for open water and the floe sizes 2 X 1 m, 4 X 2 m and 15 X 10 m at both sites and therefore the means were equal. Yet in the previous analysis, the values obtained for these size categories were not considered reliable (except open water) and so could not be expected to be found consistently in the track. The results of the analyses would seem to indicate that while the means were equal between both sites, they could not be considered reliable numbers, and hence not truly represent the floe size distribution expected for the track.

For brash and the floe sizes 7 X 4 m, the variances in distribution were not equal and hence the means were not equal between the two profile sites. This finding concurred with the previous observation that the floe size distribution for brash and 7 X 4 m floes were indeed different between the two sites.

In case two, the variances in ice piece distribution between the two runs were found to be equal only for the floe sizes 2 X 1 m and 4 X 2 m. In the confidence analysis the size

TABLE 4.9

NULL HYPOTHESIS TESTING:
PROFILE SITES 1 AND 2, JUNE 05 AND 06

Null Hypothesis: No difference in the means of ice piece distribution between profile Sites 1 and 2 (run 1)

Confidence Level: 90%

Ice Piece Size	SITE 1 $\bar{x}_1$*	SITE 1 $\bar{s}_1$*	SITE 2 $\bar{x}_2$*	SITE 2 $\bar{s}_2$*	Result	Comment
Open Water	4.5	4.56	4.05	4.17	Accept	The variance in ice piece size and distribution are equal and there is no difference between the sites.
Brash	51.25	20.58	31.75	9.50	Reject	The variances in ice piece distribution are not equal and there is a difference in distribution between the sites.
2 X 1 m	16.25	11.91	16.75	5.45	Accept	As for open water.
4 X 2 m	13.0	11.85	14.55	6.47	Reject	As for brash.
7 X 4 m	9.0	2.08	24.0	8.68	Reject	As for brash.
15 X 10 m	6.0	15.0	9.0	9.68	Accept	As for open water.

* $\bar{x}$ = mean value of % total cover of track by particular ice piece size.

* $\bar{s}$, = sample standard deviation

TABLE 4.10

NULL HYPOTHESIS TESTING:
PROFILE SITE 2, JUNE 06

Null Hypothesis: No difference in the means of ice piece distribution between runs 1 and 2

Confidence Level: 90%

Ice Piece Size	RUN 1 $\bar{x}_1$*	RUN 1 $\bar{s}_1$*	RUN 2 $\bar{x}_2$*	RUN 2 $\bar{s}_2$*	Result	Comment
Open Water	4.0	4.17	1.5	3.28	Reject	The variance in ice piece distribution are not equal and there is no difference in distribution between runs 1 and 2.
Brash	31.75	9.50	60.25	11.30	Reject	As above.
2 X 1 m	16.25	5.45	17.25	8.66	Accept	The variances in ice piece distribution are equal and there is no difference in distribution between runs 1 and 2.
4 X 2 m	14.5	6.47	13.65	7.12	Accept	As above.
7 X 4 m	24.0	8.68	5.6	7.53	Reject	The variances in ice piece distribution are not equal and there is a difference in distribution between runs 1 and 2.
15 X 10 m	9.0	9.68	1.75	4.38	Reject	As above.

* $\bar{x}$ = mean value of % total cover of track by particular ice piece size.

* $\bar{s}$ = sample standard deviation

category 4 X 2 m was considered reliable and so the results indicate that this floe size could be expected to be found consistently in the track. No consistency was observed in the confidence level tests for the 2 X 1 m category and the test results indicate that although the means are equal at both sites, they are not reliable numbers. It would seem that although logically correct inferences can be made on the basis of small samples, the results may well involve considerable errors and confidence levels may not have been appropriately chosen, and hence the seeming contradiction in results.

From these analyses, it seemed that there was no positive correlation in the results. One wonders if this might indicate that the bow shape had little or no influence on the size and distribution of the broken ice floes, and that other parameters played a more dominant role. In laboratory work conducted by CRREL researchers (CRREL 85-22, 1985) this hypothesis was also observed. Their observations on level ice breaking using a wedge(s) to simulate typical icebreaker bow designs established that the variables that may affect floe size distribution characteristics were ice thickness, ice strength, the dimension of the length of the floe piece and velocity. In their studies where only velocity was varied, no systematic variation of ice piece distribution was observed. Their findings indicated that additional laboratory studies on ice-breaker bow shapes were required and that detailed field investigations, including mechanical properties in relation to ice thickness were needed. The CRREL work did not mention the effect of propellor milling of ice which is undoubtedly a major contributing factor for the results obtained in these full-scale trials using the M.V. Arctic. Because the ship was almost continually ramming the level ice, it was breaking up the track which resulted in the redistribution and likely break-up of the broken ice pieces that were left in the track during icebreaking of the virgin ice.

The findings of the statistical analyses indicate the need for more specific ship and ice data. This requires that future field studies be carried out in close cooperation with the shipboard activities. The actions of the ship must be better known in relation to the resulting ship track.

4.4 Cusp Spacing Investigation

Each of the two test sites were characterized for cusp spacing as well as for cracks in the adjacent level ice. For both sites, the M.V. Arctic was engaged in level ice ramming tests which required the vessel to back up the track for some distance to build up speed before ramming the unbroken ice ahead.

4.4.1 Methodology

Both port and starboard sides were profiled, concurrent with the measurements of the track width at regular 10m intervals. A baseline was established along each profile site with markers at regular measured intervals. The following aspects of the track edge were investigated:

1. Measured cusp length and width at selected points. **Figure 4-9** illustrates the nomenclature for cusp length and width. Mapping of the rest of the profile with respect to the survey baseline.

2. Mappping of cracks in the ice with respect to the track edge and baseline.

3. Photographs of track edge from ground level and from helicopter at 100 feet altitude.

4. Position and length of ice features along the track edge including sections of crushed ice, "notches" in the track profile and other features of interest.

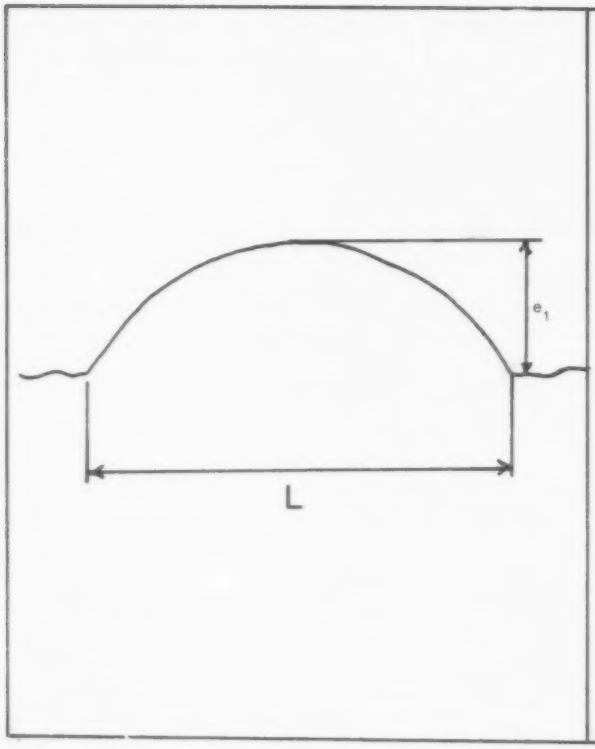
5. Local ice thickness, freeboard and snow depth adjacent to the track in a few selected locations.

A total of 1000 m was profiled in detail at Site 1 and 200 m for Site 2.

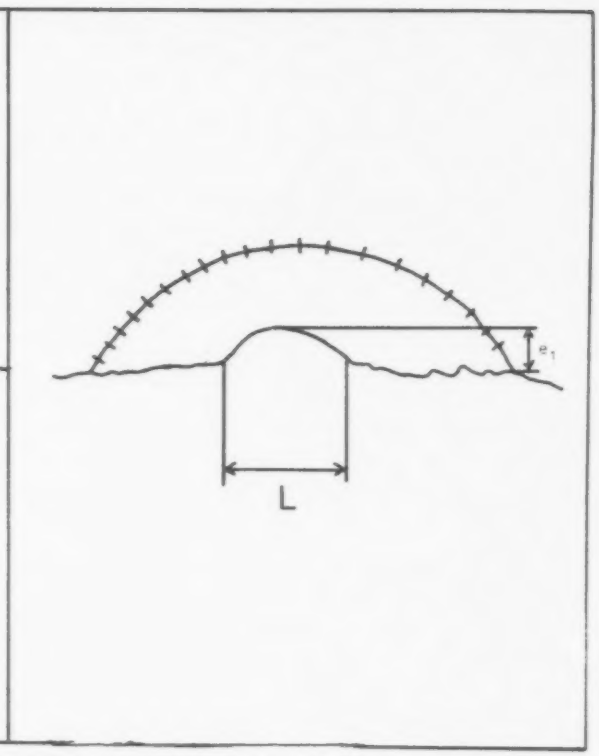
4.4.2 Cusp Description

Plates 4-1 and 4-2 illustrate in a relative sense and from an aerial perspective the configuration of the track edge for the two test sites. Several observations are apparent from a study of these photographs and of other photographs covering not only the detailed profile sites but also the remaining sections of the track:

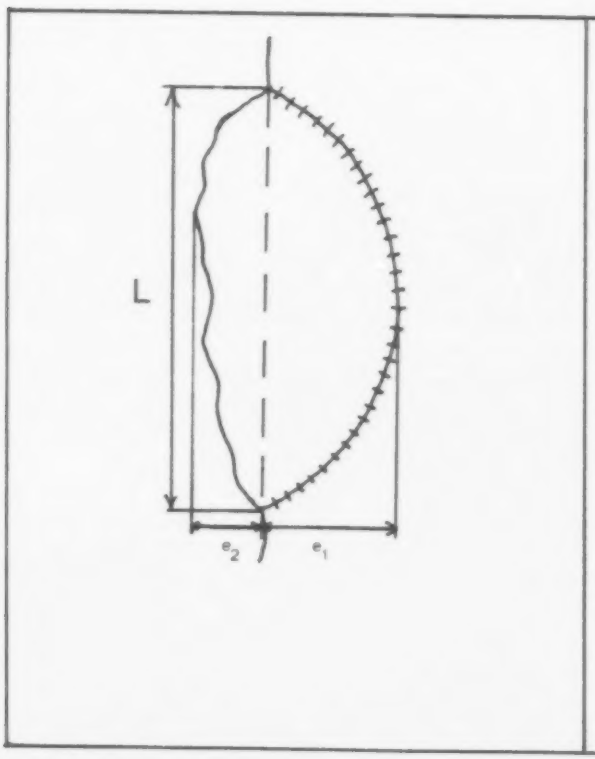
FIGURE 4-9
M.V. ARCTIC SHIP TRACK CUSP SPACING CHARACTERIZATION



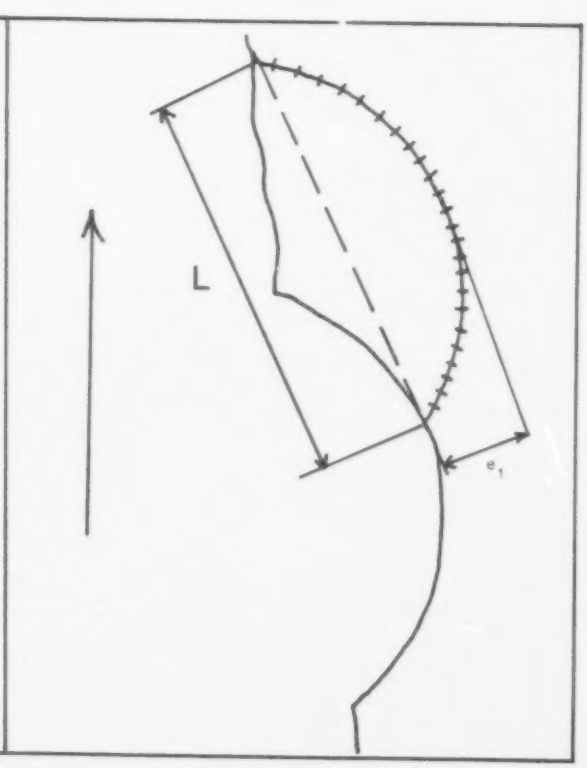
OPEN CUSP



CUSP WITHIN A CUSP



CLOSED CUSP



CUSP BUILDING ON A CUSP

1. The configuration of cusps between the port and starboard sides is not symmetrical. **Plate 4-8** illustrates pictorially the lack of symmetry between the port (right) and starboard (left) sides of the track.

2. Short sections of both sides of the track are composed of upturned blocks and/or crushed ice. The upturned blocks are cusps which have separated from the level ice but were not moved into the center of the track. **Plate 4-9** shows the ruptured blocks at the outside edge of the track behind the ship. The crushed ice sections are typically located along relatively straight and narrow sections of the track edges.

   These segments where the ice edge clearly consists of crushed ice have formed from some lateral force exerted by the ship as it moved through the ice or perhaps from pulverizing a broken piece of cusp of ice against the track side. The level ice behind the crushed ice was observed to be intact with no evidence of cracks.

3. The length and maximum width of the cusps is highly variable. Although not measured in the two test sections, some of the cusps exceeded 60 m in length. Maximum widths up to 12 m from the length axis were measured.

4. Ice thickness measurements taken at several locations adjacent to the track edge confirmed that some ice pieces had been pushed underneath the unbroken level ice. Several holes were drilled at increasing distances away from the track edge and generally showed that most of the holes within 2-3 m of either side of the track had ice underneath the level ice. In some holes within 1-2 m of the track edge, two separate layers of broken ice pieces were detected below the level ice thickness. Ice pieces underneath the level ice were not detected in holes drilled 5-6 m away from the track edge.

5. The cusps along the track edge exhibit a highly variable curvature, although their shapes were more or less elliptical with a few extreme triangular cusps also observed.

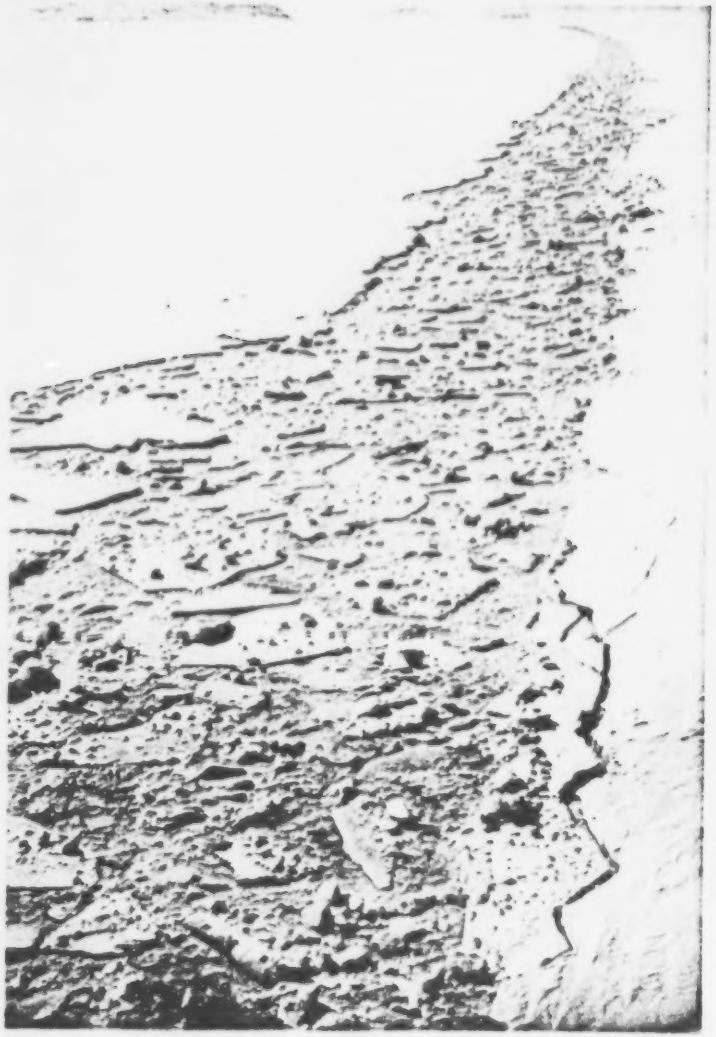


PLATE 4-8: ASSYMETRICAL SHIP TRACK CUSPING PATTERN - NEAR SITE 2 LOOKING NORTH

PLATE 4-9: UPTURNED ICE BLOCKS IN CUSP-STARBOARD SIDE NEAR SITE 2, LOOKING SOUTH

Based on the inspection at the track edges and the cracks in the ice cover adjacent to it, the cusps that result from the M.V. Arctic in a level ice ramming transit mode can be divided into several distinct types:

1. Open Cusps - completely severed.
2. Closed cusps - partially severed.
3. Cusps building on cusps.
4. Smaller cusps created within larger ones.
5. Incomplete cusps.
6. Notches.

As noted earlier, there were sections of the track where no cusping pattern was apparent. Some, but not all these sections had crushed ice banking the track edge.

Table 4.11 summarizes the characteristics of each of these types of cusps. From the detailed site investigations, there appeared to be no set pattern to the sequence, size or frequency of these cusp types. Most of the cusp types can be characterized as the shape of an ellipse which has a major axis as the cusp "length", and an eccentricity e_1, as the cusp "width". These two parameters were measured and profiled along both sides of the track. In general, the ship track sides can be characterized as a series of these cusping patterns, randomly distributed and interspersed with straight sections.

4.4.3 Cusp Measurement Data

The port and starboard sketches of the track sides made in the field were transcribed to scaled drawings for the analysis of cusp length and width. These sketches were augmented by selected measurements of cusp length and width in the field.

TABLE 4.11

DESCRIPTION OF VARIOUS CUSP TYPES OBSERVED IN ADMIRALTY INLET - JUNE 1986

	CUSP TYPE	SHAPE	TYPICAL LENGTH RANGE (m)	TYPICAL WIDTH RANGE (m)	REMARKS
1.	Open cusp	Elliptical	10-50m	1-6m	Ice piece completely severed and moved into center of track leaving clear cusp pattern. No evidence of radial or circumferencial cracks in level ice adjacent to cusp edge.
2.	Closed cusp	Elliptical	10-40m	1-12m	Incomplete breakoff of ice piece from level ice. Ice piece remains within the cusp. No evidence of radial or circumferencial cracks in level ice adjacent to cusp edge.
3.	Cusps building on cusps	Elliptical/ Triangular highly variable	3-30m	0.5-0.8m	New cusp formed by ice cracking in a cusping pattern adjacent to a developing open or closed cusp. Ice piece may or may not remain. A result from radial or circumferencial cracks in level ice adjacent to type 1 or 2 during their formation.
4.	Cusps within a cusp	Elliptical Larger eccentricity	0.5-12m	1-4m	Cusp breaks off within a cusp already forming. Usually observed in closed cusps where ice piece has remained.
5.	Incomplete cusping	Elliptical (tending towards)	-	-	Consist of elliptical cracks in the ice which do not appear to extend back to the side of the track. Rarely seen but thought to exist in smaller percentage.
6.	Notches	Triangular	-	-	Usually result at the junction of two major cusps along the track edges and where only a corner of the ice piece is removed.

Tables 4.12 and 4.13 present the reduced data for the two test sites for both port and starboard sides. Length and width of each identified cusp was measured as follows:

Length (L) - measured between the end points of the arc defining the cusp. These end points were generally located at the track edge or at the intersection point with adjacent cusps.

Width (e_1) - maximum distance measured away from the track perpendicular to the line defining the cusp length dimension and the arc defining the cusp. Generally the maximum was located in the central section of the arc, but sometimes the cusp shape was skewed so that the arc resembled a teardrop rather than an ellipse.

In the case of closed cusp types, two widths were measured; one the same as e_1 and the other e_2 the maximum perpendicular distance from the length line to the edge of the ice piece towards the track. Addition of e_1 with e_2 equalled the maximum width of the remaining ice piece.

There are several observations to note from the tables:

1. The frequency, spacing and pattern of cusp types was random along both sides.

2. The number of identifiable cusps between port and starboard was signficantly different.

3. The spacing and pattern of cusp types was different between port and starboard.

4. No statistically significant difference was observed in the length and width of cusp types 1, 2 or 3. The average length and width of cusp type 4 (i.e. cusps within cusps) was about 50% less than types 1, 2 or 3.

TABLE 4.12

PROFILE SITE 1
CUSP MEASUREMENT TABLE
(1000m Section)

	PORT						STARBOARD					
	DIST. (m)	L (m)	E_1 (m)	E_2 (m)	$\frac{L}{E_1}$	CUSP TYPE	DIST. (m)	L (m)	E_1 (m)	E_2 (m)	$\frac{L}{E_1}$	CUSP TYPE
1	10.0- 50.3	40.3	4.6	6.6	8.8	2	35.3- 50.0	14.7	3.6	-	4.1	1
2	63.3-102.0	38.6	6.0	4.7	6.4	2	50.0- 68.6	18.0	5.3	-	3.4	1
3	88.0-118.7	31.0	0.5	4.0	-	3	68.6- 86.6	18.0	2.8	-	6.4	1
4	118.7-156.0	37.3	6.6	-	5.7	1	231.3-239.4	7.6	0.8	-	9.5	1
5	156.0-187.3	32.0	4.6	-	7.0	1	247.4-270.0	22.3	4.3	6.0	5.2	2
6	187.3-219.3	32.0	-	-	-	2	270.0-277.7	7.6	3.0	0.3	2.5	2
7	222.0-238.0	16.6	3.2	-	5.2	1	284.6-291.0	6.6	2.0	1.6	3.3	2
8	225.0-245.0	20.0	5.3	1.6	-	3	307.6-346.0	35.3	6.6	3.7	5.3	2
9	245.0-256.0	10.6	2.0	2.6	5.3	2	351.8-387.6	35.3	8.7	3.7	4.1	2
10	256.0-279.0	22.7	4.0	2.6	5.7	2	360.0-376.3	16.0	3.0	1.0	5.3	4
11	288.0-307.0	18.6	3.3	1.3	5.6	2	405.6-432.0	26.0	2.3	-	11.3	1
12	347.0-361.0	14.0	2.6	-	5.4	1	450.0-473.6	23.7	4.9	-	4.8	1
13	361.0-386.0	25.3	5.3	2.0	4.8	2	473.6-485.9	12.7	3.0	-	4.2	1
14	386.0-405.0	18.6	2.0	2.0	9.3	2	485.9-490.0	4.1	1.6	0.0	2.6	2
15	436.0-454.0	17.3	2.0	1.3	8.7	2	490.0-492.6	2.6	2.2	0.2	-	3
16	470.0-496.0	26.0	6.0	0.3	4.3	2	499.4-536.7	36.6	6.6	-	5.5	1
17	482.0-505.0	22.6	2.0	2.0	-	3	530.0-584.3	55.3	7.3	5.0	-	3
18	505.0-524.0	18.6	2.0	-	9.3	1	584.3-593.7	10.0	2.6	-	3.8	4
19	521.0-553.0	31.3	4.3	3.0	7.3	2	584.3-635.1	50.0	8.0	-	6.3	1
20	550.0-586.0	36.0	3.3	3.4	-	3	591.3-600.0	9.0	1.6	-	5.6	4
21	581.0-599.0	18.0	3.0	4.0	-	3	635.1-676.7	41.3	5.3	3.2	7.8	2
22	588.0-621.0	32.6	5.3	-	6.2	1	635.1-659.0	23.6	5.3	-	4.5	4
23	621.0-660.0	38.6	6.5	1.8	5.9	2	651.0-657.3	6.6	2.0	-	-	3
24	656.0-691.0	34.0	4.0	5.3	-	3	669.0-691.0	21.7	3.7	-	5.9	1
25	688.0-719.0	37.3	4.0	3.3	9.3	2	669.0-672.4	3.6	0.6	-	6.0	4
26	712.0-749.0	35.0	6.6	4.0	-	3	672.4-677.0	4.6	1.8	-	2.6	4
27	766.0-796.0	30.0	4.0	1.0	7.5	2	677.6-681.0	4.0	1.0	-	2.5	4
28	793.0-812.0	19.3	2.0	3.6	-	3	681.0-691.0	10.3	2.0	-	5.2	4
29	835.0-844.0	10.0	2.0	0.4	5.0	2	708.0-725.6	17.3	1.3	-	13.3	1
30	844.0-858.0	13.7	2.7	2.0	5.1	2	725.6-731.6	5.6	1.0	-	5.6	1
31	848.0-854.0	6.0	2.3	-	2.6	4	731.6-743.4	12.6	3.0	-	4.2	1
32	860.0-875.0	15.0	4.3	1.6	3.7	2	747.2-767.3	20.6	3.2	-	6.4	2
33	860.0-866.0	7.3	2.0	0.7	3.7	4	757.7-767.3	10.7	1.2	1.0	8.9	3
34	866.0-875.0	8.3	2.1	0.7	4.0	4	767.3-793.3	25.3	3.5	-	7.2	1
35	875.0-933.0	56.6	5.3	2.6	10.7	2	784.0-	N/A			-	3
36	924.0-952.0	26.7	3.0	4.3	-	3	823.0-837.4	14.3	1.3	-	11.0	1
37	941.0-949.0	8.0	1.3	-	6.2	4	844.0-880.0	35.3	5.0	-	7.1	2
38	957.0-971.0	24.0	3.3	2.0	7.3	2	852.0-874.0	21.6	2.1	-	-	3
39	969.0-975.0	6.3	1.6	-	3.9	4	880.0-896.7	17.0	2.5	-	6.8	1
40	967.0-990.0	22.6	3.3	0.8	-	3	896.7-911.0	14.0	1.0	-	14.0	1
41							922.3-941.0	18.0	3.0	-	6.0	1
42							942.0-947.7	5.0	3.2	0.0	1.6	2
43							947.7-968.3	20.3	5.1	1.0	4.0	2
44							968.3-992.5	24.1	2.0	-	12.0	1

TABLE 4.13

PROFILE SITE 2
CUSP MEASUREMENT TABLE
(1000m Section)

	PORT						STARBOARD					
NO.	DIST. (m)	L (m)	E_1 (m)	E_2 (m)	$\frac{L}{E_1}$	CUSP TYPE	DIST. (m)	L (m)	E_1 (m)	E_2 (m)	$\frac{L}{E_1}$	CUSP TYPE
1	5.3- 16.5	11.8	3.0	4.8	3.9	2	8.0- 15.3	9.0	1.8	-	5.0	1
2	43.5- 64.0	20.5	2.9	-	7.1	1	15.3- 25.0	8.5	3.1	-	2.7	1
3	64.0- 72.5	9.0	3.0	-	3.0	4	25.0- 33.6	8.7	2.3	-	3.8	1
4	72.5- 80.0	8.0	2.0	-	4.0	4	30.5- 41.6	11.5	3.8	1.1	-	3
5	80.0- 87.5	8.0	1.9	-	4.0	4	46.6- 58.0	11.5	1.4	-	8.2	1
6	56.5- 87.5	32.0	4.0	2.0	8.0	2	58.0- 60.8	3.0	0.8	-	3.8	4
7	87.5-125.0	39.0	5.8	-	6.7	2	60.8- 66.5	6.3	2.0	-	3.1	4
8	130.0-146.8	17.0	2.5	-	6.8	1	54.5- 74.0	20.5	5.5	2.0	-	3(0)
9	146.8-159.5	12.5	0.8	-	15.6	1	75.9- 83.0	7.3	2.1	-	3.5	2
10	185.0-200.0	15.5	3.0	3.0	5.1	2	86.5- 93.5	7.0	2.3	1.6	-	3
11							89.2-103.5	14.5	4.7	-	3.1	1
12							125.0-138.0	13.3	2.4	2.5	5.5	2
13							138.0-157.0	19.5	3.0	0.2	6.5	2
14							140.0-151.5	11.5	3.0	-	3.8	4
15							173.5-183.5	10.0	1.9	-	5.3	1

Table 4.14 presents some descriptive statistics on the cusp lengths by cusp type for Sites 1 and 2, for port and starboard respectively plus a combination. There are two observations that are apparent from this table:

1. Cusp lengths were apparently greater on the starboard side.

2. Cusp lengths were greater for Site 1 than Site 2.

It is not readily obvious why there should be such differences in the data. The lengths of the sampling sites are relatively small (1000 m and 200 m) compared to the length of the M.V. Arctic and in hindsite a longer sampling site might have been required to obtain a statistically valid database. There was insufficient knowledge of the ship's forward and backward motions during the level ice ramming tests through these two sections of the track.

Because the ship was backing and ramming, it is likely that most sections of the track were transitted by the M.V. Arctic at least three times:

1. First, as initial icebreaking by the ship in the forward ramming mode.

2. Second, during reversing of the ship back down the broken track at least one and sometimes two ship lengths.

3. Third, in reversing engines and moving forward down the broken track prior to ramming the unbroken ice ahead.

The net forward progress of the M.V. Arctic during any particular ram ranged from 200-300 m, or about one-half a ship's length with an average ram penetration of 248 m. A ramming cycle where the reverse cycle exceeded a ship length could have conceivably resulted in some sections of the track being transitted by the M.V. Arctic up to five times. The effects of this transit mode on the configuration of the track cannot be documented in detail because the exact forward penetration and backing distances for each ram in relation to the resulting track were not documented in sufficient detail.

It would appear that there was at least some lateral motion of the M.V. Arctic perpendicular to the track axis. This lateral motion may have resulted during the backing and forward motion portions of the ramming cycle, when the

TABLE 4.14

CUSP LENGTH ANALYSIS RESULTS
(Units in Metres)

	CUSP TYPE 1			2			3			4			1+2		
SITE NO	MEAN	S.D	n	MEAN	S.D.	n	MEAN	S.D.	n	MEAN	S.D.	n	MEAN	S.D.	n
1 PORT SIDE	25.2	9.9	6	26.2	12.6	17	26.0	7.2	9	11.0	9.4	6	25.9	11.8	23
1 STAR-BOARD SIDE	19.6	10.4	18	21.2	14.0	11	20.4	19.2	6	10.1	6.8	8	20.2	11.7	29
1 BOTH SIDES COMBINED	21.0	10.4	24	24.3	13.2	28	23.8	13.0	15	10.5	7.7	14	22.7	11.7	52
2 PORT SIDE	16.7	4.0	3	24.6	13.0	4	-	-	-	8.3	0.6	3	21.2	10.4	7
2 STAR-BOARD SIDE	10.4	2.3	6	13.4	6.1	3	13.0	6.9	3	6.9	4.3	3	11.4	3.9	9
2 BOTH SIDES COMBINED	12.5	4.2	9	19.8	11.5	7	-	-	-	7.6	2.8	6	15.7	8.7	16

M.V. Arctic hit some pieces of ice in the broken track causing a small lateral motion component in the ship's velocity path. The evidence for this lateral motion was observed in the occasional short sections of track where the ice had clearly been crushed against the ship's hull, resulting in the sections of crushed ice along the track edge.

4.4.4 Ice Thickness Profile Data

Measured ice thickness data taken adjacent to the track sides are summarized in **Table 4.15**. Two holes were drilled on either side of the track while one hole was drilled through one of the pieces in the track center.

As noted earlier, ice pieces were detected underneath the level ice in the holes drilled closest to the track edge. It appeared that the lateral extent of these pieces underneath the level ice was in the order of a few metres. In holes drilled further away the field party was unable to detect any pieces lodge underneath the level ice. Increases in the freeboard in the level ice adjacent to the track from ice pieces udnerneath were negligible, in the order of a few centimetres. For example, at station 200 m, site 1, the difference in freeboard for the ice station closest to the track was +6 cm.

TABLE 4.15

ICE THICKNESS DATA ADJACENT TO SHIP TRACK

SITE #	LOCATION	HOLE #	DISTANCE FROM TRACK EDGE	ICE THICK-NESS (m)	FREE-BOARD (m)	REMARKS
1	STATION 200 m	1	6 m to starboard side	1.74	0.17	
		2	3 m to starboard side	1.70	0.23	Ice piece underneath
		3	2 m to port side	1.65	0.13	Blocks detected at 2.3 m
		4	5 m to port side	1.73	0.13	
1	STATION 0 m	1	4 m to starboard side	1.69	0.14	
		2	2 m to starboard side	1.75	0.17	Blocks underneath
		3	3 m to port side	1.69	0.17	Blocks underneath
		4	9 m to port side	1.66	0.13	
		5	center of track	1.74	0.41	Free floating piece, blocks underneath
2	STATION 0 m	1	1 m to starboard side	1.78	0.14	Bottom of block 1 at 2.05 m depth of block 2 at 2.43 m depth
		2	5 m to starboard side	1.70	0.11	
2	STATION 200 m	1	5 m to starboard side	1.75	0.19	
		2	2 m to starboard side	1.80	0.23	Blocks underneath
		3	2 m to port side	1.71	0.18	Blocks underneath
		4	5 m to starboard side	1.70	0.17	
		5	center of track	1.70	0.17	

4.5 Ridge Ramming Tests

The ramming trials were carried out on June 7th in level ice conditions at the site indicated on Figure 4-1. The M.V. Arctic rammed the ridge at the optimum keel depth point marked by the field team. A 3 m high wooden marker had been erected on the sail of the ridge and the approach path to the ridge designated by garbage bags.

The vessel successfully rammed the ridge with no difficulty at a speed of 7 knots and then decellerated within 2 minutes to 1 knot and continued at that speed for another 3 minutes before coming to a complete stop. The vessel managed to penetrate a total of 248 m before coming to a halt (Melville Shipping Ltd., 1986)

Plates 4-10 to 4-12 were taken as the M.V. Arctic approached the ridge near survey section 5. Plate 4-10 shows the bow imprint of the vessel where she stopped some 60 m back from the ridge sail. The M.V. Arctic broke a channel to the front of the ridge, reversed astern one full ship's length and then proceeded down the broken track at full power. Plate 4-11 shows the vessel advancing on the ridge. The ridge sail was marked by the line of upturned ice blocks.

Plate 4-12 is a photo of the field team at survey section 7 waiting for the ram tests to commence. The wooden marker was erected near the optimum ram point to assist the vessel in manoeuvering into position. The rubble piles in the foreground mark the section 6 cross survey line.

From the ice properties collected under task 3, the pre-probe study, it was found that the ridge consisted of unconsolidated ice blocks aligned along a narrow north-south axis. The ease at which the vessel was able to ram and penetrate past the ridge indicated that the ridge had a negligible effect on the vessel's performance. A video recording of the M.V. Arctic ramming the ridge is presented under separate cover.

PLATE 4-10: Bow imprint of the M.V. Arctic Near The Shear Ridge

PLATE 4-11: M.V. Arctic Approaching the Shear Ridge for Ramming Tests

PLATE 4-12

Field Team Waiting at the Shear Ridge. The marker indicated the optimum ramming point for the M.V. Arctic.

5.0 PROGRAM SUMMARY

The M.V. Arctic performance tests were successfully conducted during the vessel's first Arctic voyage of 1986 from Montreal to Nansivik. The trials were carried out in Baffin Bay between May 31st and June 4th and in Admiralty Inlet from June 5th to 8th. In support of the performance program, an ice physical property program was conducted. The program was coordinated by Canarctic Shipping Company Ltd., with Melville Shipping Ltd. personnel supervising the trials tests and Norland Science and Engineering Ltd. carrying out the ice properties program.

5.1 Ice Conditions

The performance of the vessel in thick first year ice exceeded the model predictions and the ship experienced little difficulty in transitting the ice conditions of Baffin Bay and Admiralty Inlet. The ice physical property data collected by the field teams provided sufficient data of high quality to enable the ship's performance in ice to be successfully determined.

Baffin Bay

The on-ice field program carried out in Baffin Bay was not as extensive as the Admiralty Inlet pre-probe program. The field team was limited by the time required to conduct the performance tests, as well as by the lack of over-ice transportation. This necessitated that all ice work be carried out in close proximity to the ship. The data sets were collected after each successful test run and provided Melville Shipping Ltd. with enough ice physical property data to classify the ice cover.

The tests were performed in thick first year ice with an average ice thickness of 1.02 $\pm$ 0.28 m and an average freeboard of 0.07 $\pm$ 0.04 m. The snow cover was 0.16 $\pm$ 0.04 m deep. Salinity values in the top 0.70 m of the ice cover averaged 5.2 $\pm$ 0.5 ppt and the flexural strength of the ice was calculated as 292.4 $\pm$ 5.6 kPa.

Admiralty Inlet

The Admiralty Inlet pre-probe program was a ten day field program. A total of fifty-three sites were measured in order to characterize the ice cover and confirm the proposed ship track selected earlier in Task 2. Of the fifty-three sites, twelve sites were studied in more detail to include ice

thickness, freeboard and snow depth, ice salinity and temperature.

The ice cover in Admiralty Inlet had an average thickness of 1.75 ± 0.1 m and a freeboard of 0.10 ± 0.02 m. It was observed from the profiling survey that the ice cover was 0.20 m thinner in a zone in the centre of the Inlet between sites 5 and 8. The average snow cover had a depth of 0.21 ± 0.5 ppt. Salinity was measured in the top 0.70 m of the ice cover and the average value for the sites was 4.7 ± 0.5 ppt. The corresponding ice temperatures averaged -5.1° ± 0.6°C. The flexural strength was found to be similar for all the sites, with an average of 443 ± 11 kPa.

The ice cover in Strathcona Sound had undergone more deterioration than observed in Admiralty Inlet. Ice thicknesses were noticeably less and the snow cover resembled corn snow. The average ice thickness was 1.49 ± 0.1m with a freeboard of 0.10 ± 0.03 m. The salinity was sampled at 2 sites and averaged 4.2 ± 0.4 ppt. The corresponding ice temperatures were -3.1° ± 0.6°C, as much as 2°C warmer than the temperatures recorded in Admiralty Inlet. The flexural strength was calculated to be 392.5 ± 43 kPa.

From past field programs conducted in 1982 and 1984, the ice conditions encountered during the vessel performance program are considered to have been typical of an average year. The stage of spring melt in both Admiralty Inlet and Strathcona Sound were consistent with the historical records. The ice thicknesses however were observed to be slightly below the values recorded for the years 1981 and 1983 and above the averages recorded for 1982 and 1984. (Lapp, 1984).

5.2 Ship Track

The M.V. Arctic successfully transitted the ice in Admiralty Inlet into the Nanisivik docksite. The main mode of transit for the vessel was continuous light ramming at full power. The average forward speed varied around 2-4 knots. Various performance tests were conducted along the track at the discretion of Melville Shipping personnel.

As part of the on-ice work, the ship track was studied to determine the effect of the new bow configuration on the track shape, width and distribution of ice pieces. Detailed field work was carried out at two representative sites. Site 1 represented a single transit track and site 2 represented an inbound and outbound track. Site 2 was studied after each passage of the ship to enable a comparison between the results from both runs and with site 1.

It was found that the mean track widths of both sites were similar and that no difference in width was observed between run 1 and 2 at site 2. The mean width for site 1 was 35.2 m and for site 2, run 1 and 2 it was 28.8 m. The variable interaction of the ice cover properties with the dynamics of the propulsion system is believed to account for the minor difference in widths recorded between the two sites. The different transit modes between the two sites is also thought to have influenced the ice breaking characteristics. At site 1 the ship performed standard rams to advance through the ice. This was found to be a slower method and the vessel changed over to transition mode rams for the remainder of the transit.

Analyses of ice piece size and distribution data using the student T distribution confidence of means tests and the null hypothesis testing gave inconsistent results. No systematic variation could be inferred from the data. Similar model-scale work carred out by CRREL researchers where velocity alone was varied with different bow designs, no correlation in ice piece cover and distribution was observed. Their conclusions were that floe size distribution was more dependent on the parameters of ice thickness, ice strength and the dimensions of the individual floe length. Their findings also indicated the need for more full-scale and model testing. In the case of the M.V. Arctic tests however, the ship was almost always reversing back down the track, allowing the propellor to mill the remaining ice pieces and push them into different patterns.

A great deal of hitherto first-time piece size and track coverage data were obtained during the field program, but its collection was not as well coordinated with the ship-board instrumentation program as it could have been. It was realized that too many ship variables existed during the data collection period, and that better correlation between ship activity and the field measurement program is necessary to better quantify the influence of the ship on the track.

Analyses of the cusp spacing configuration revealed that the port and starbord sides were not symmetrical and that ice length and maximum width of the cusps were not highly variable. As well the cusps exhibited a highly variable curvature, but could be considered elliptical. A few triangular cusps, or notches, were also recorded. Altogether it was observed that several distinct types of cusps were formed by the transit mode of the M.V. Arctic:

- open cusps - completely severed
- closed cusps - partially severed
- cusps building on cusps

- cusps within larger ones
- incomplete cusps
- notches

In addition to the cusps formed, short sections of the track on both sides were composed of upturned blocks and/or crushed ice. These segments of crushed ice edge were formed by both a lateral force exerted by the lesser of the track as it moved through the ice; resulting in any broken pieces of ice positioned adjacent to the track edge to become pulverized.

In assessing the cusping configuration between sites 1 and 2, it was observed that cusp-lengths were greater on the starboard side for each site and that the cusp lengths of Site 1 were greater than those lengths recorded for Site 2. It is not readily obvious there was such a difference in the data. Further detailed site investigations revealed no set pattern to the size, sequence or frequency of the cusp types. The cusping patterns seemed to be randomly distributed. The inability to draw any definite conclusions reflects (in hindsite) the poor liaison between the on-ice team and the instrumentation team.

The ridge ramming tests were successfully completed with no difficulty. The M.V. Arctic rammed the ridge at a speed of 7 knots along a section of the ridge with a keel depth of 3.20 m. The ship decelerated within 2 minutes to a speed of 1 knot and continued through the ridge for a distance of 248 m before coming to a complete stop. The results of the ridge penetration ram were similar to level ice ramming.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The M.V. Arctic performance trials conducted in Baffin Bay and Admiralty Inlet during May and June 1986 were a complete success. The level ice physical property program carried out in support of the performance tests provided quality data to permit the ship's performance in ice to be determined. From the results of the program it can be concluded that:

1. The level ice conditions in Baffin Bay and Admiralty Inlet were typical of spring conditions.

2. The ice conditions in Admiralty Inlet were consistent with ice conditions recorded for previous years. The ice thicknesses were 0.10 m less than the average values recorded in 1981-83 and 0.10 m greater than the 1984-85 data.

3. The ice cover in Strathcona Sound had undergone more deterioration than observed in Admiralty Inlet and this was reflected in the lower flexural strengths obtained from temperature and salinity data.

4. The shear ridge selected for the ridge ramming test consisted of unconsolidated first year, grey-white ice blocks. The ridge keel was measured to be 3.20 m at the point where the vessel rammed the ridge.

5. The ship track route selected in task 2 of the program was the final route chosen by the field team. The M.V. Arctic successfully negotiated the ship route into Nanisivik with little difficulty. The principal transit mode was ramming at 100% power with an average forward speed of 2 knots.

6. It was found that the mean track width varied slightly between sites 1 and 2 but that for runs 1 and 2 at site 2 no difference was recorded. The difference in widths between the 2 sites is believed to represent the variable interaction of the ice cover properties with the dynamics of the ship propulsion system.

7. It was observed that higher percentages of small ice pieces were found in the track at site 1 and site 2, run 2. It is believed that this reflects the effects of standard rams used in transitting through site 1 and the result of moving astern up the track at site 2 before the second run.

8. Statistical analyses on the ice piece distribution data using the student T distribution confidence of means test and the null hypothesis test indicated that the data are, on the whole, not reliable at a confidence level of 90% and therefore not truly representative of the ice piece distribution expected to be found consistently in the track. The null hypothesis, which stated that the means were equal between sites and between runs at site 2, had seemingly conflicting results with the confidence of means tests. It would seem that although it is possible to make logically correct inferences on the basis of small samples, the results may well have involved considerable errors and the confidence levels may not have been appropriately chosen.

9. The cusping patterns along the ship track could be classified into six types. The two most common cusp types were open cusps, wherein the ice piece was removed, and only the outline was visible, and closed cusps where the ice piece remained. The predominant cusp shape was an ellipse with the major axis defined as the cusp length and the eccentricity or one-half the minor axis, defined as the cusp width.

10. Cusp lengths and widths were found to vary widely. Cusp lengths were, on average, larger on the starboard side and greater at Site 1 than Site 2.

11. Ice pieces were detected underneath the level ice within 3m of the track edge, sometimes in more than one layer. No pieces were detected underneath the level ice at distances of 5m or more from the track edge.

12. The bow shape had little influence on the ice piece distribution and that other parameters such as ice thickness, ice strength, ship velocity and floe size dimension had a more dominant influence. Perhaps most dominant was the reverse cycles of the ship during ramming when the propellor milled some of the remaining ice pieces in the track.

RECOMMENDATIONS

1. While the data collected for this program provided quality information to assess the ship performance in level ice, it did not provide sufficient data to properly assess the effect of the new bow configuration on the ship track. It is recommended that for future work, the ship operating mode be closely monitored with the on-ice work in order to provide more data on teh actions of the ship with respect to the ice. This would be needed to ascertain the effect of the bow on the characteristics of the track.

2. It is recommended that longer sections of the track be characterized, at least up to several ship lengths. This is in order to properly assess the effects of the vessel ramming and backing up several times over the same sections of the track. It was found that this component of the ship transitting mode had a major impact on the ship track configuration but could not be properly quantified in the short sections of track analysed.

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APPENDIX A

SALINITY VS DEPTH PROFILES
BAFFIN BAY SITES

TABLE A.1

METHOD FOR CALCULATING THE
FLEXURAL STRENGTH OF SEA ICE

The flexural strength of sea ice may be obtained by a combination of two equations. The first for brine volume and the second for flexural strength as a function of brine volume.

From Frankenstein and Garner (1967) the relationship of brine content to mean ice salinity and temperature is:

$$V = s \left[\frac{-49.185}{T} + 0.532 \right] \cdot 10^{-3}$$

where V = Brine volume

S = Salinity of ice (ppt)

T = Temperature (°C)

From Weeks and Assur (1967) the relationship of flexural strength of sea ice to flexural strength of fresh water ice and brine volume is:

$$\sigma = \sigma^{\circ} \left[1 - 2\sqrt{v} + v\right]$$

where σ = Flexural strength of sea ice (kPa)

σ° = Flexural strength of fresh water ice (kPa)

V = Brine volume for equation

From Frederking (1979) and Frankenstein (1970) the values of flexural strength of fresh water ice of 700 kPa and 760 kPa are found. An average value of 730 kPa may be used.

The flexural strength, versus the salinity and temperature of the ice, has been plotted in the attached diagram.

TABLE A.2

AVERAGE SALINITY VALUES
BAFFIN BAY TESTS

SITE	DEPTH(m)	SALINITY (ppt)
1	0.00 - 0.10	7.0 ± 1.4 ppt
	0.10 - 0.50	5.5 ± 0.71
	0.51 - 0.90	4.5 ± 0.72
3a	0.00 - 0.10	5.5 ± 2.1
	0.10 - 0.50	5.3 ± 0.6
	0.50 - 0.83	6.3 ± 1.5
3b	0 00 - 0.10	5.5 ± 0.7
	0.10 - 0.50	4.7 ± 0.6
	0.50 - 0.83	5.3 ± 1.1
4	0.00 - 0.10	5.6 ± 0.4
	0.10 - 0.50	5.7 ± 0.6
	0.50 - 0.80	4.7 ± 0.6
	0.90	8.0 ± 0.0
5	0.00 - 0.10	5.8 ± 0.4
	0.10 - 0.50	6.2 ± 0.8
	0.50 - 1.00	5.7 ± 0.6
	1.00 - 1.16	5.3 ± 0.6
6	0.00 - 0.10	7 ± 1.4
	0.10 - 0.50	5.2 ± 0.8
	0.50 - 0.87	6.0 ± 1.0
7*	0.00 - 0.10	8.3 ± 1.1
	0.10 - 0.50	4.3 ± 0.5
	0.50 - 0.82	4.8 ± 0.8

* at entrance to Admiralty

FIGURE A.1.

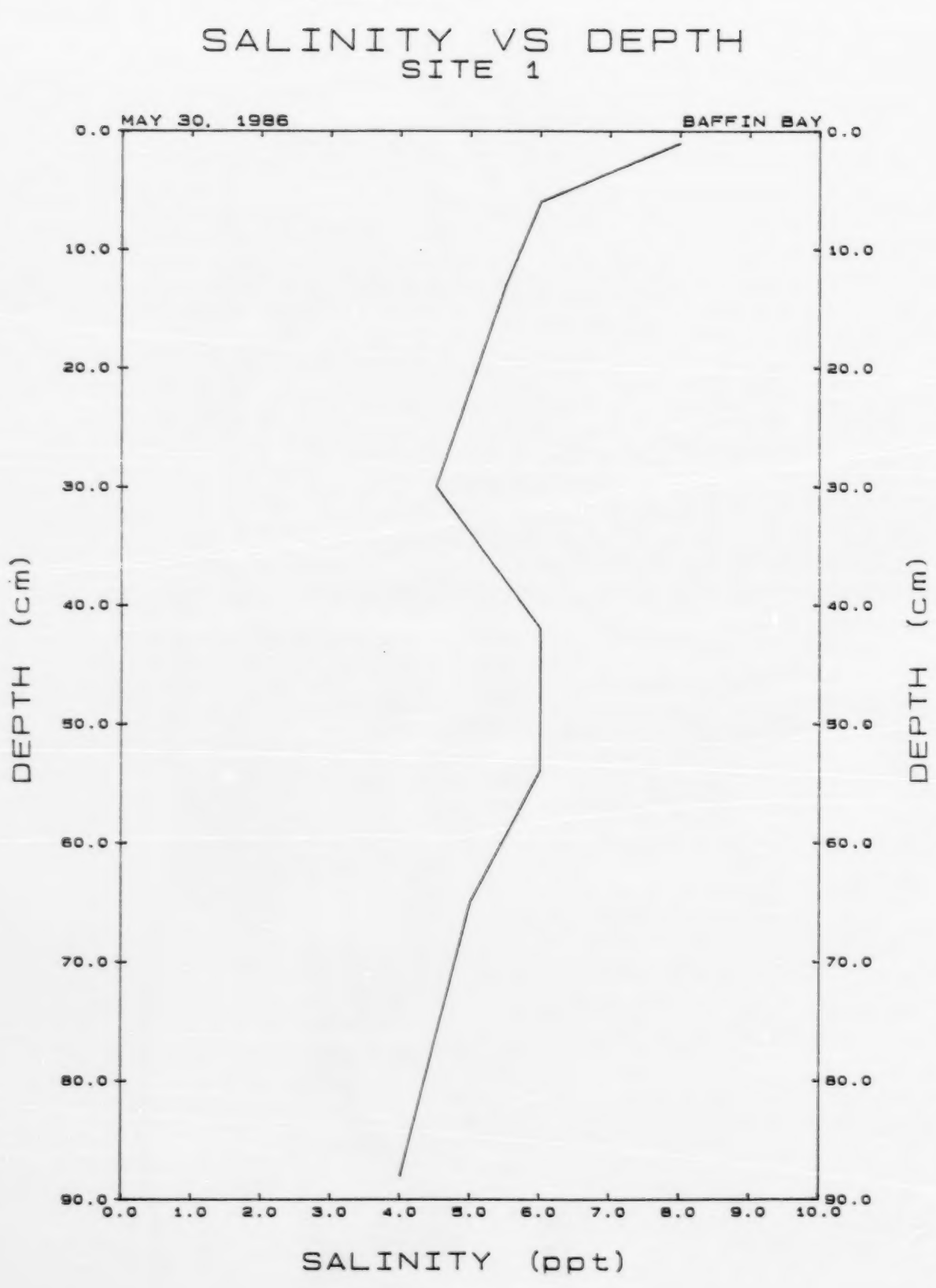
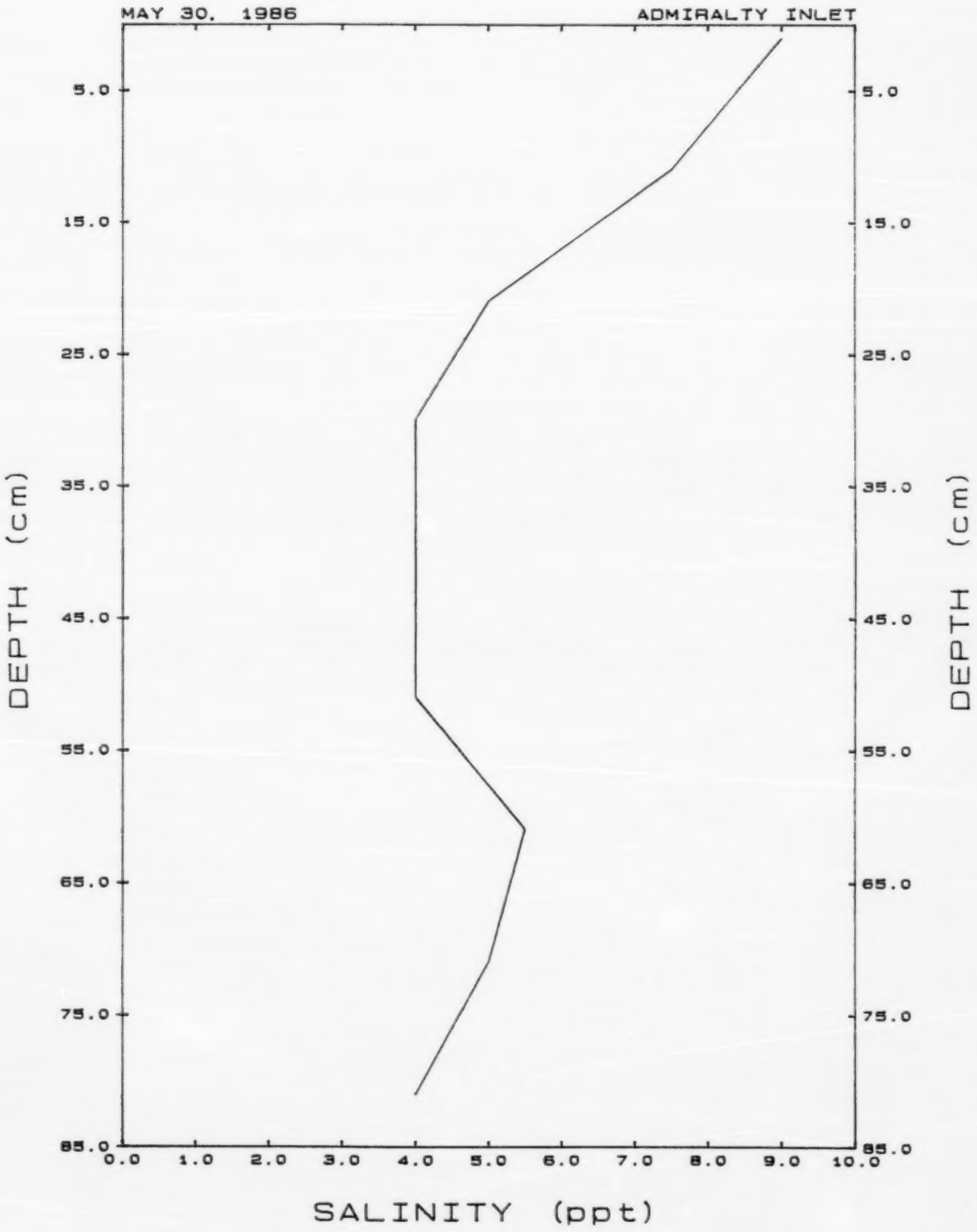

SALINITY VS DEPTH
SITE 1
MAY 30, 1986
BAFFIN BAY
DEPTH (cm)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
SALINITY (ppt)
SALB1

FIGURE A-2

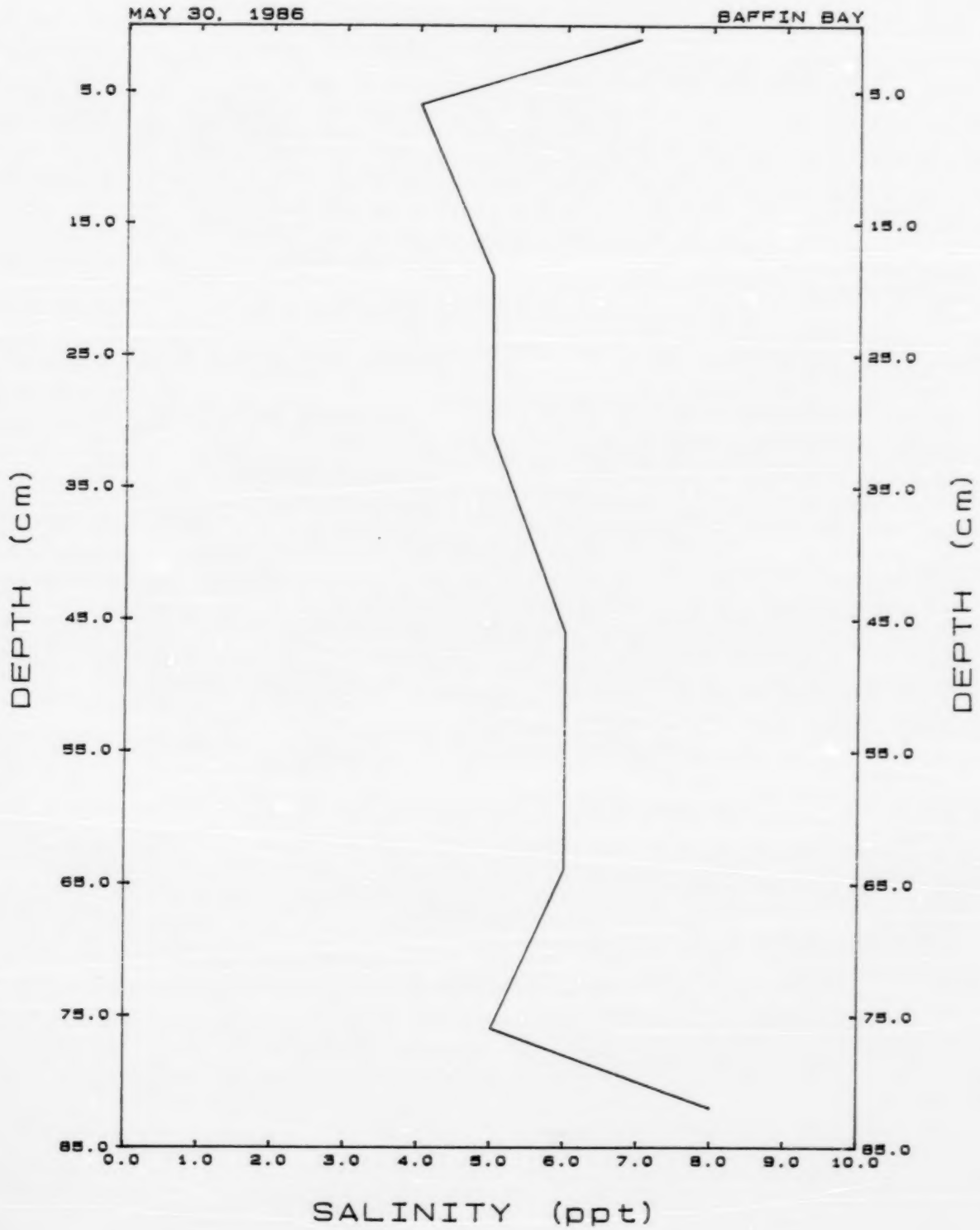
SALINITY VS DEPTH
SITE 7



SAL87

FIGURE A-3

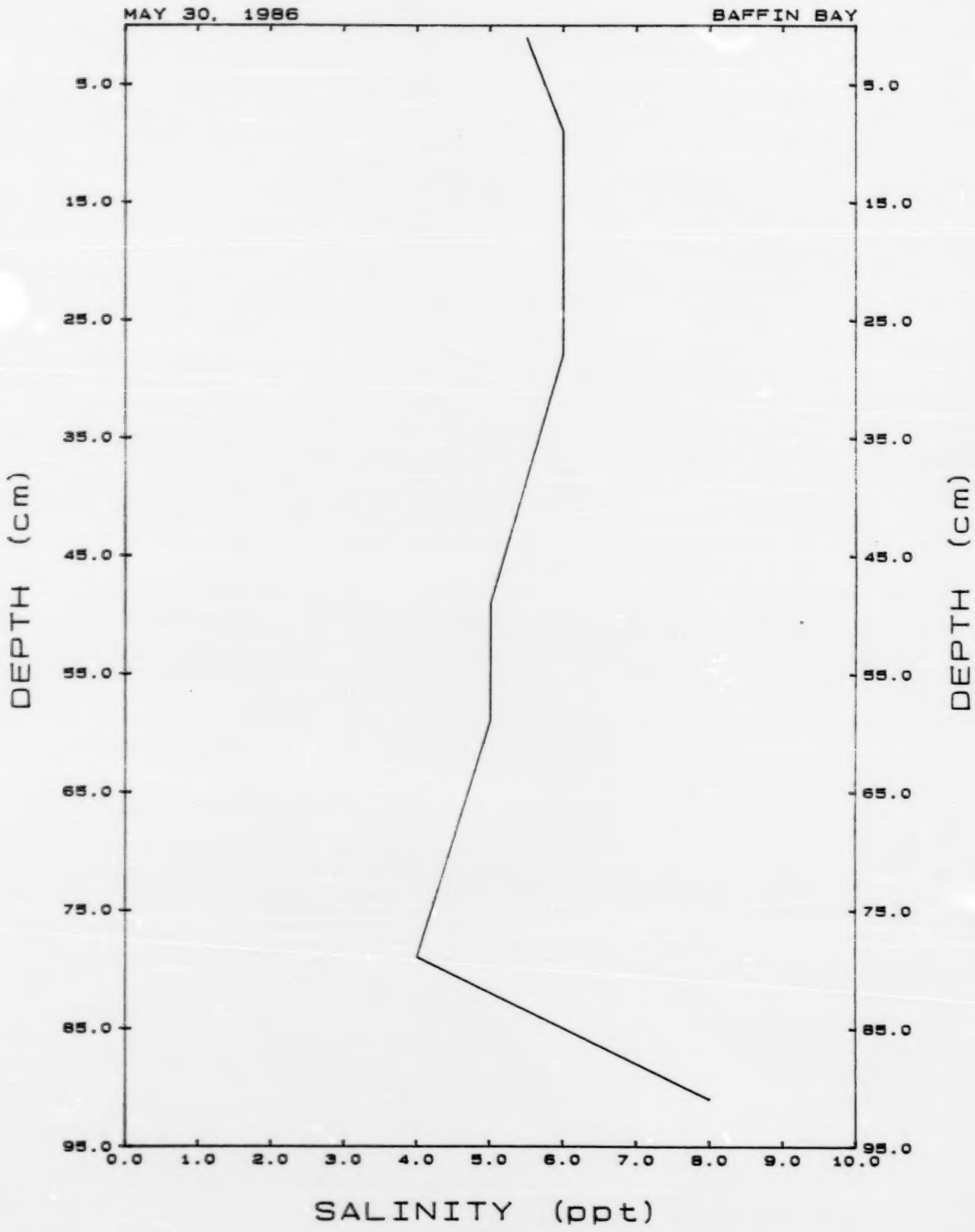
SALINITY VS DEPTH
SITE 3A



sslb3a

FIGURE A-4

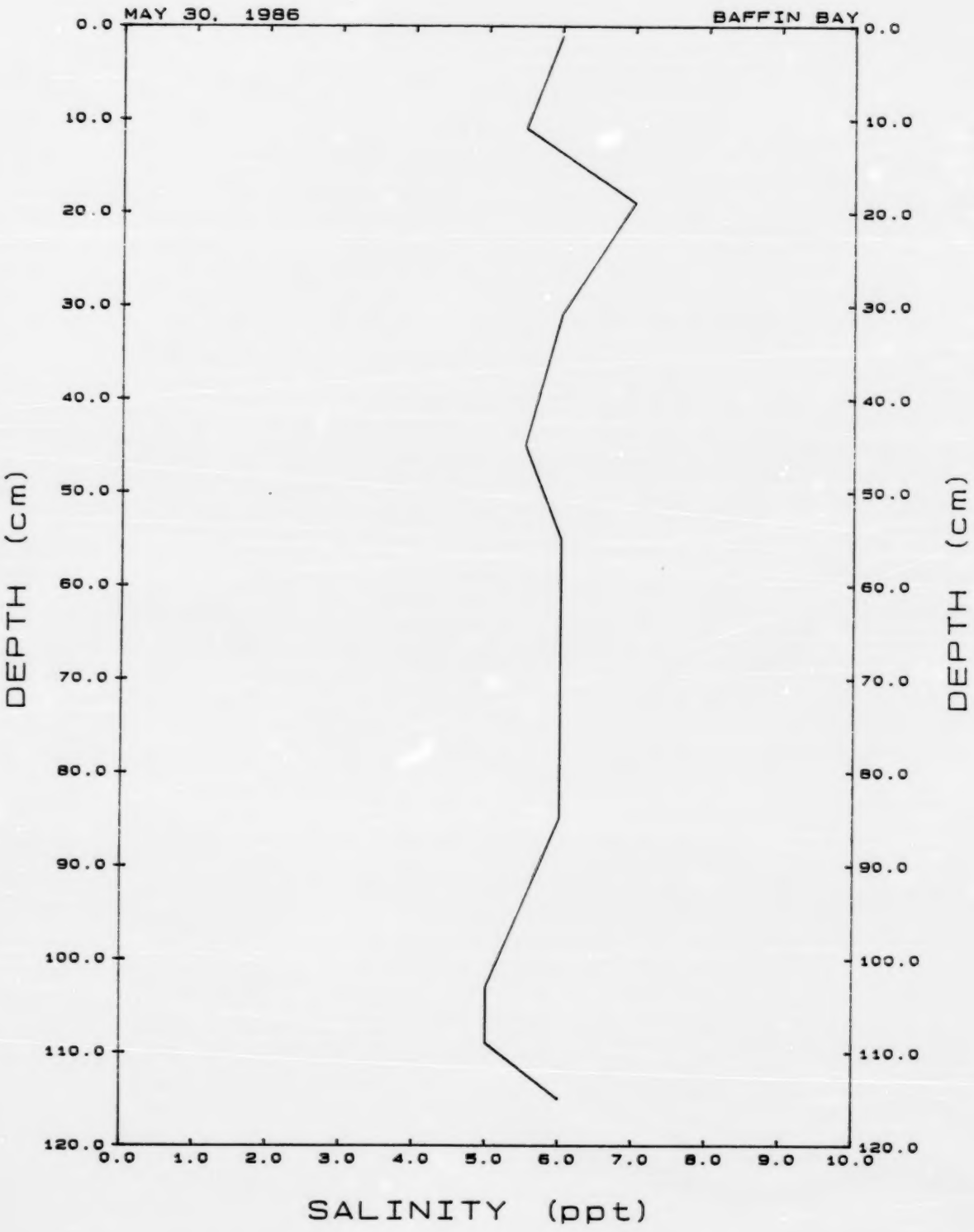
SALINITY VS DEPTH
SITE 4



SAL84

FIGURE A-5

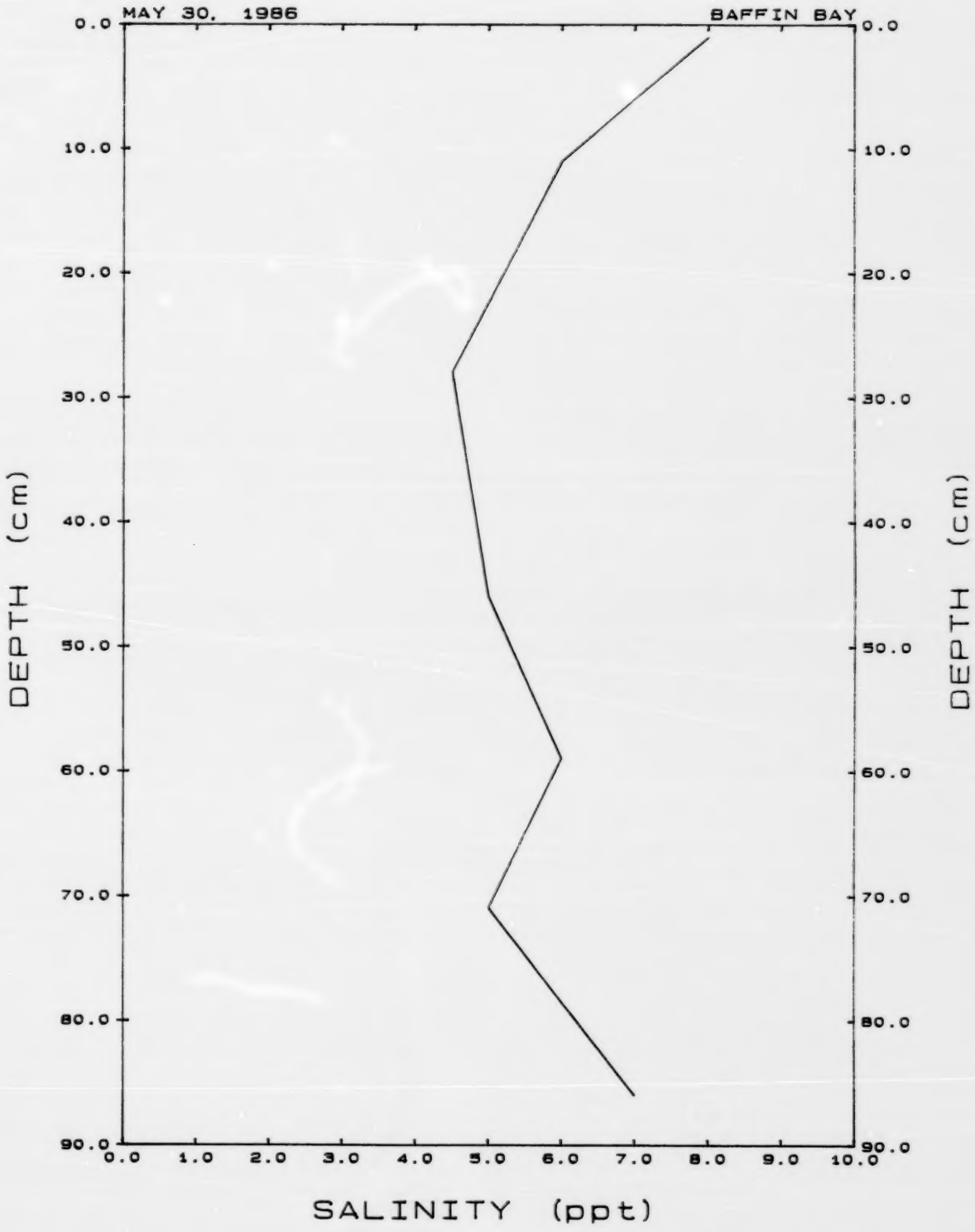
SALINITY VS DEPTH
SITE 5



SAL85

FIGURE A-6

SALINITY VS DEPTH
SITE 6



SAL86

APPENDIX B

SALINITY VS DEPTH PROFILES
ADMIRALTY INLET SITES

TABLE B.1

AVERAGE SALINITY VALUES
ADMIRALTY INLET TESTS

SITE	DEPTH(m)	SALINITY (ppt)
RIDGE 3S	0.00 - 0.10	3.9 ± 0.55
	0.10 - 0.50	5.2 ± 1.2
	0.50 - 1.00	3.14 ± 0.22
	1.00 - 1.71	3.10 ± 0.41
1	0.00 - 0.10	6.3 ± 1.4
	0.10 - 0.50	3.8 ± 0.5
	0.50 - 1.00	4.4 ± 0.3
	1.00 - 1.73	3.5 ± 0.9
2	0.00 - 0.10	6.26 ± 0.7
	0.10 - 0.50	4.7 ± 0.5
	0.50 - 1.00	4.5 ± 0.8
	1.00 - 1.67	4.0 ± 0.4
3	0.00 - 0.10	7.4 ± 0.9
	0.10 - 0.50	5.6 ± 0.5
	0.50 - 1.00	4.9 ± 0.4
	1.00 - 1.75	5.0 ± 0.9
4	0.00 - 0.10	7.2 ± 0.7
	0.10 - 0.50	5.8 ± 0.9
	0.50 - 1.00	4.5 ± 0.5
	1.00 - 1.64	4.5 ± 0.8
5	0.00 - 0.10	7.4 ± 0.7
	0.10 - 0.50	5.1 ± 1.7
	0.50 - 1.00	4.3 ± 0.4
	1.00 - 1.61	3.8 ± 0.5
6	0.00 - 0.10	7.7 ± 0.4
	0.10 - 0.50	5.0 ± 1.0
	0.50 - 1.00	4.4 ± 0.8
	1.00 - 1.64	4.5 ± 0.5
7	0.00 - 0.10	8.2 ± 0.5
	0.10 - 0.50	6.6 ± 1.3
	0.50 - 1.00	5.5 ± 0.3
	1.00 - 1.59	4.5 ± 0.7

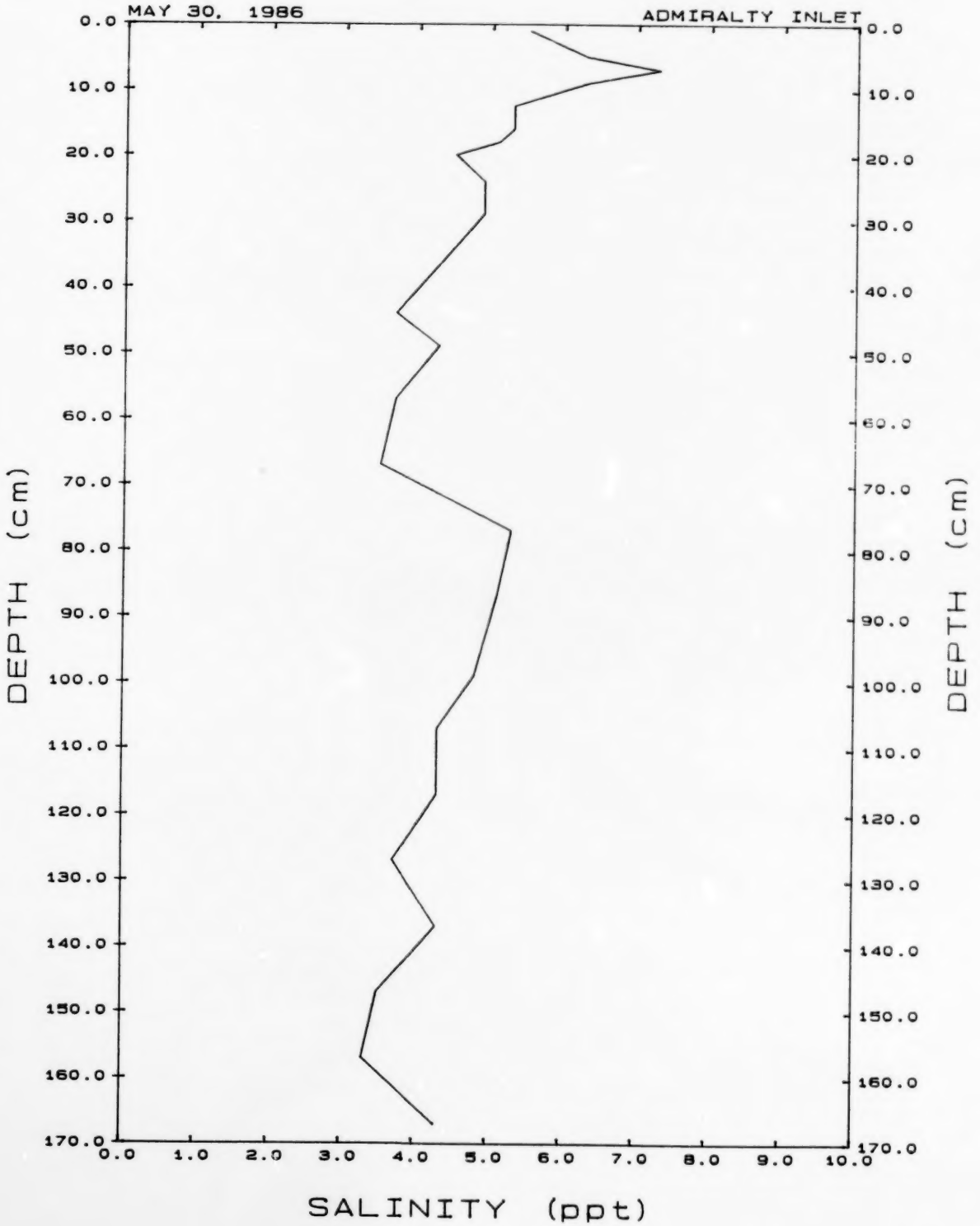
TABLE B.1

AVERAGE SALINITY VALUES
ADMIRALTY INLET TESTS (cont'd)

SITE	DEPTH(m)	SALINITY (ppt)
8	0.00 - 0.10	8.3 ± 0.5
	0.10 - 0.50	6.1 ± 0.9
	0.50 - 1.00	4.9 ± 0.3
	1.00 - 1.42	4.5 ± 0.2
9	0.00 - 0.10	10.5 ± 0.3
	0.10 - 0.50	6.7 ± 1.4
	0.50 - 1.00	4.4 ± 0.4
	1.00 - 1.70	3.7 ± 0.4
10	0.00 - 0.10	7.1 ± 0.3
	0.10 - 0.50	6.1 ± 0.8
	0.50 - 1.00	4.3 ± 0.6
	1.00 - 1.57	4.4 ± 0.7
HOLE 46	0.00 - 0.10	4.9 ± 0.5
	0.10 - 0.50	4.8 ± 0.6
	0.50 - 1.00	4.2 ± 0.3
	1.00 - 1.48	4.6 ± 1.1
HOLE 51	0.00 - 0.10	4.6 ± 1.3
	0.10 - 0.50	3.9 ± 0.5
	0.50 - 1.00	4.0 ± 0.4
	1.00 - 1.50	3.7 ± 0.9

FIGURE B-1

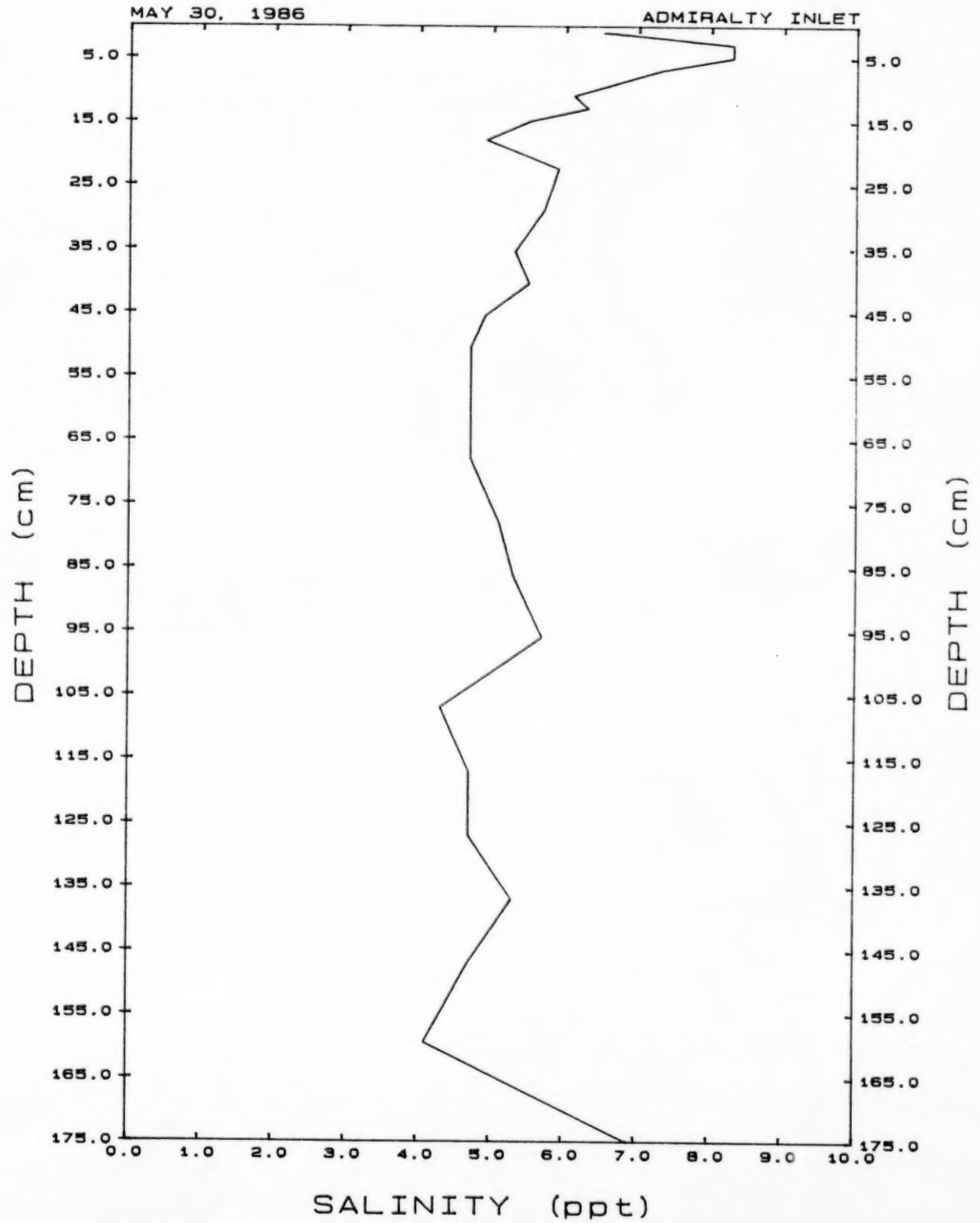
SALINITY VS DEPTH
SITE 2



SAL2

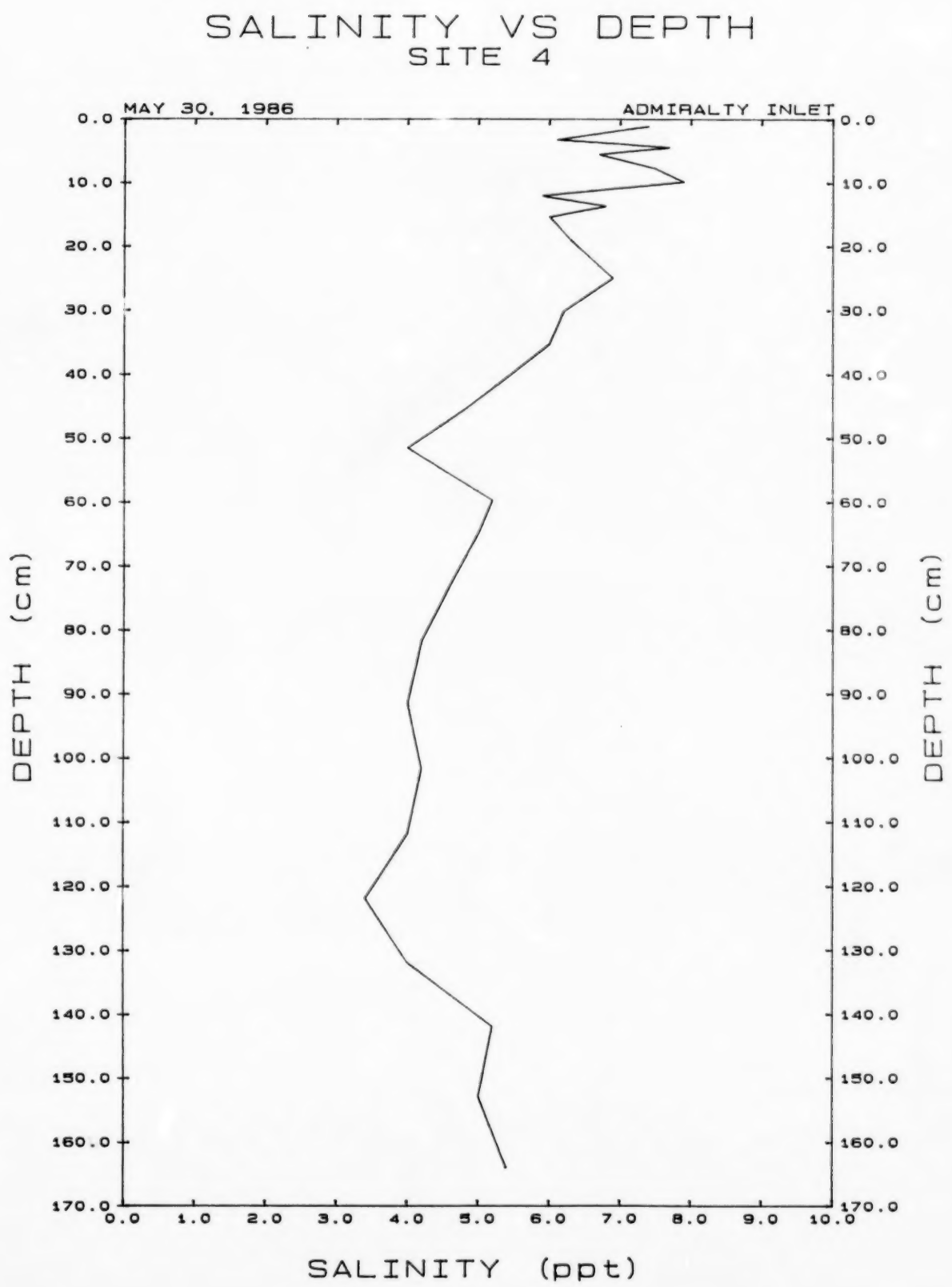
FIGURE B-2

SALINITY VS DEPTH
SITE 3



SAL3

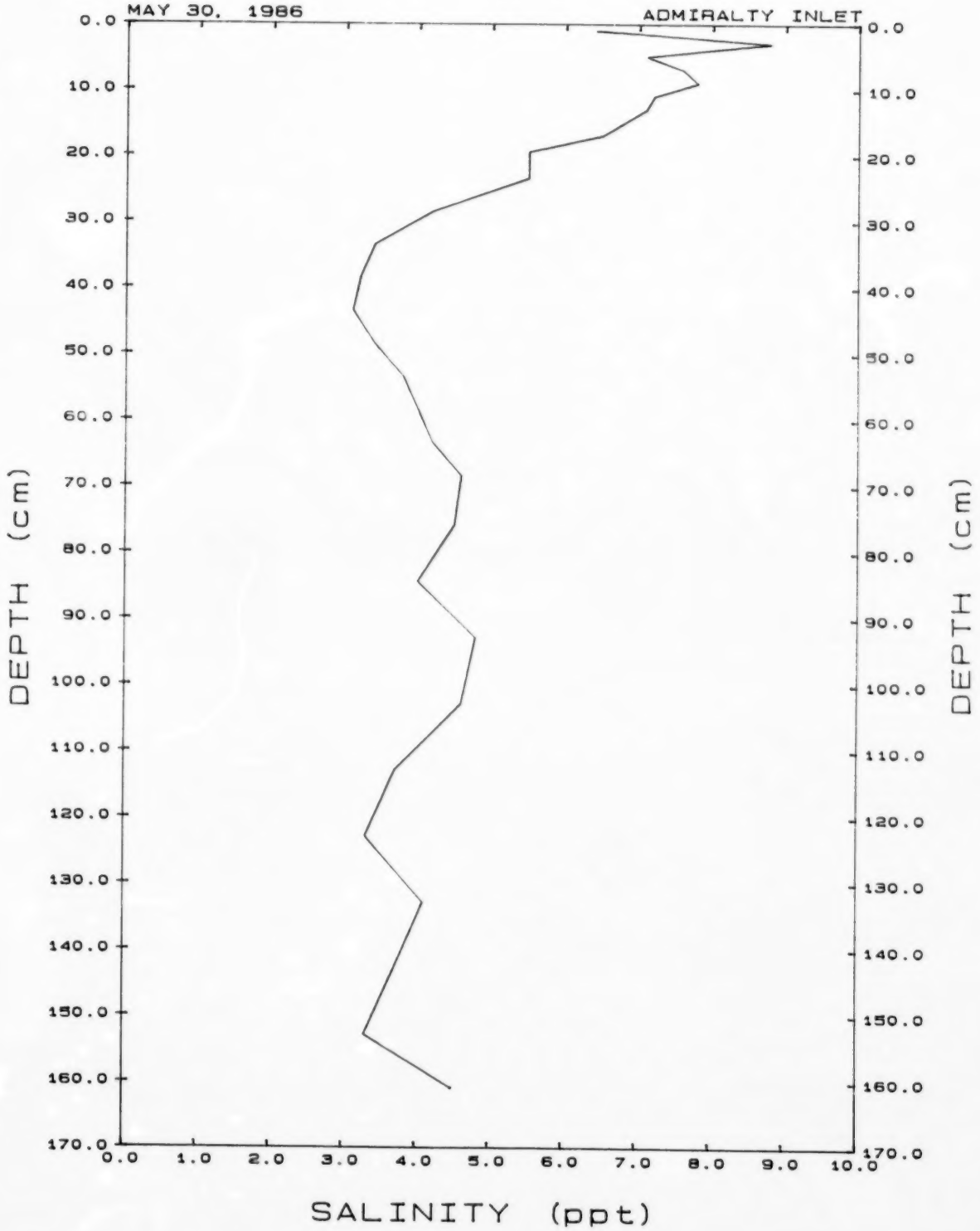
FIGURE B-3



SAL4

FIGURE B-4

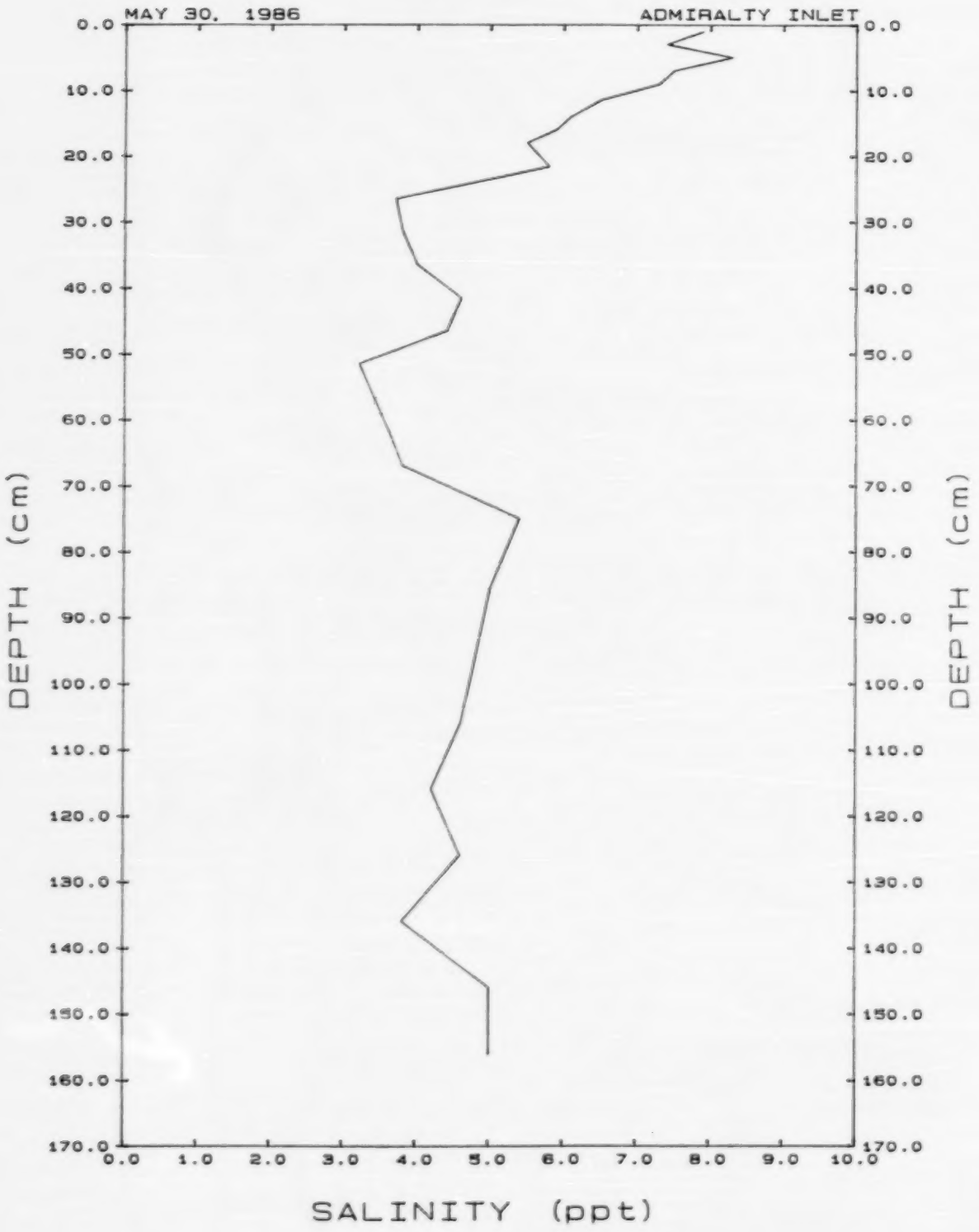
SALINITY VS DEPTH
SITE 5



SAL5

FIGURE B-5

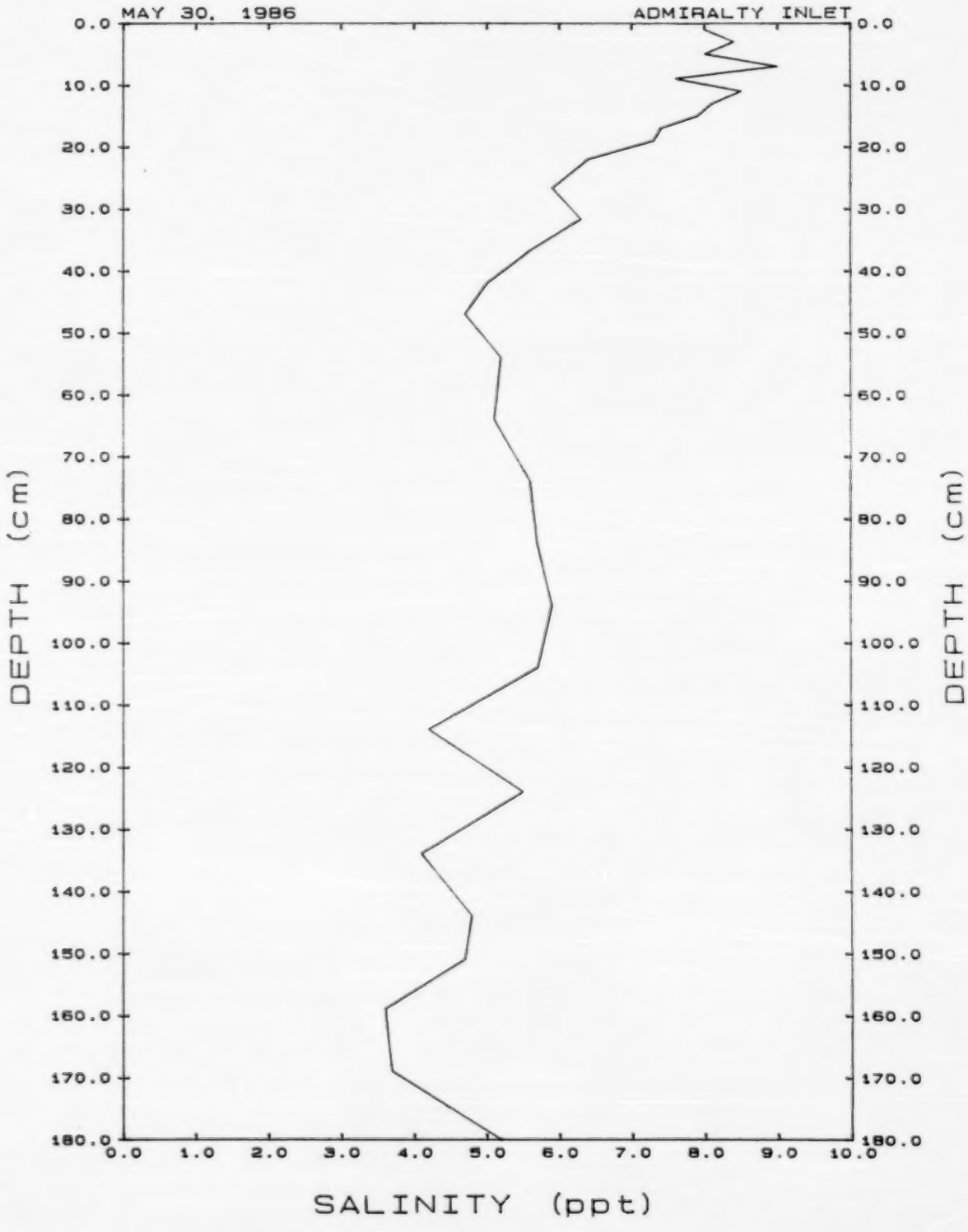
SALINITY VS DEPTH
SITE 6



SAL6

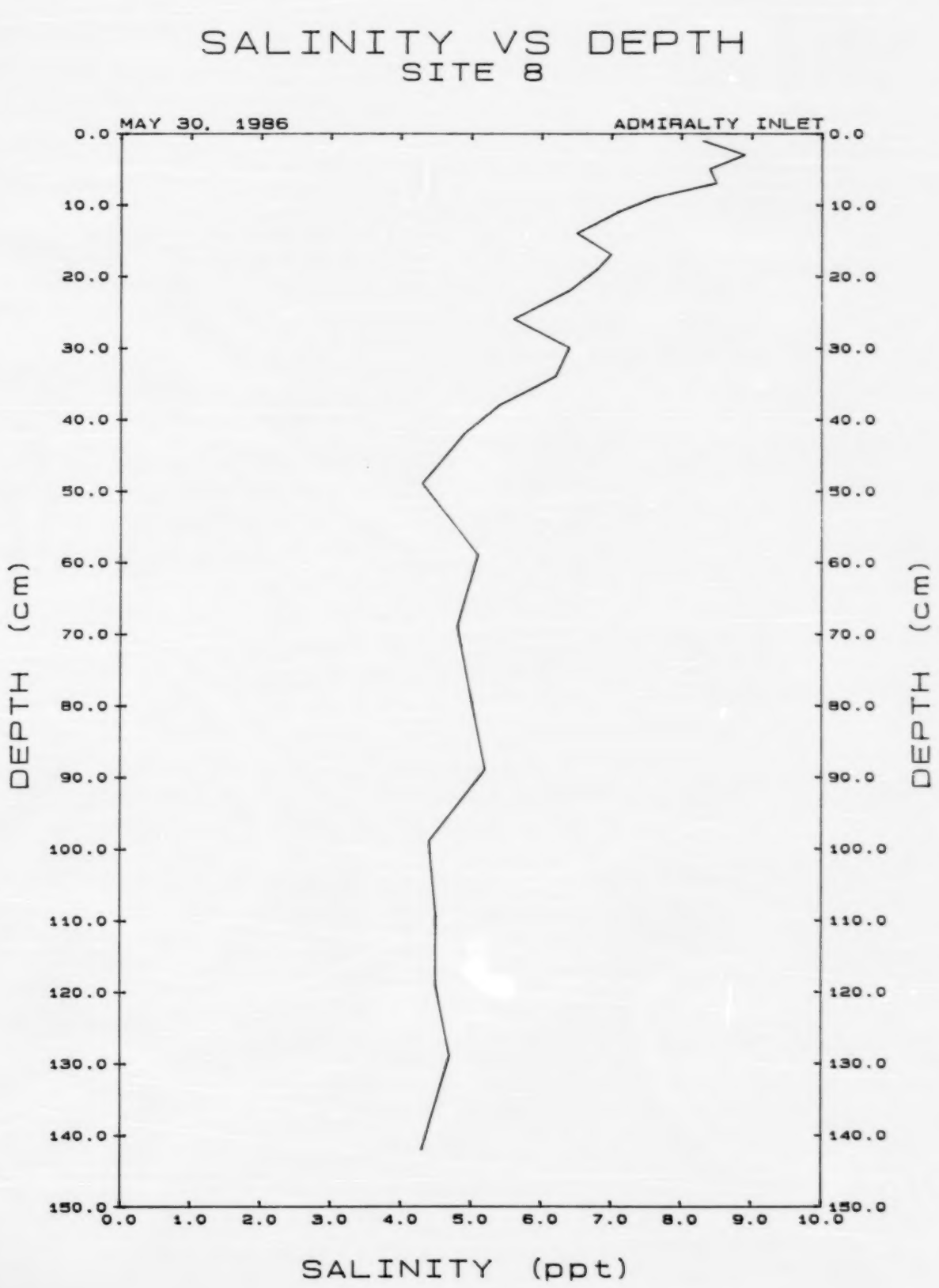
FIGURE B-6

SALINITY VS DEPTH
SITE 7



SAL7

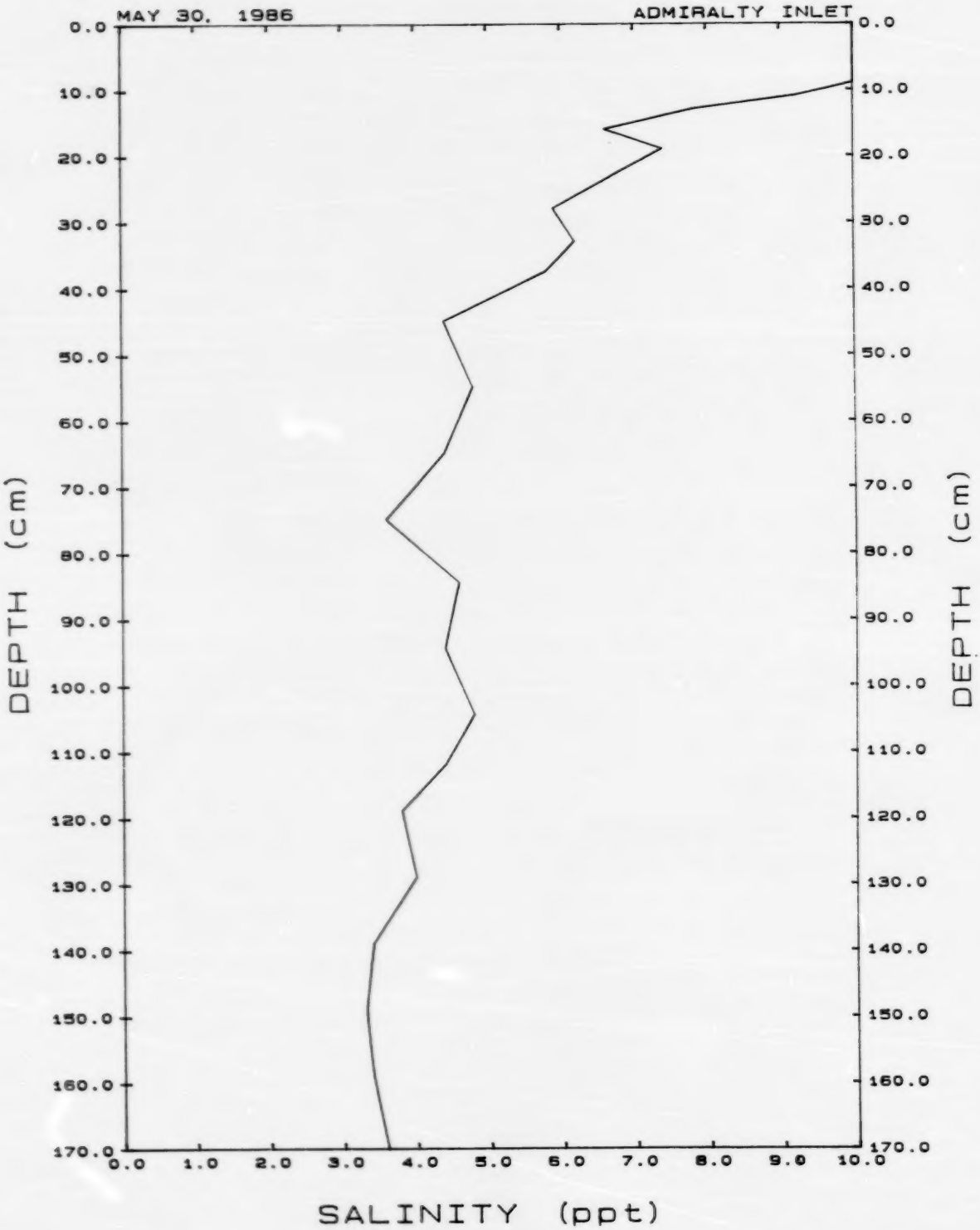
FIGURE B-7



SAL8

FIGURE B-8

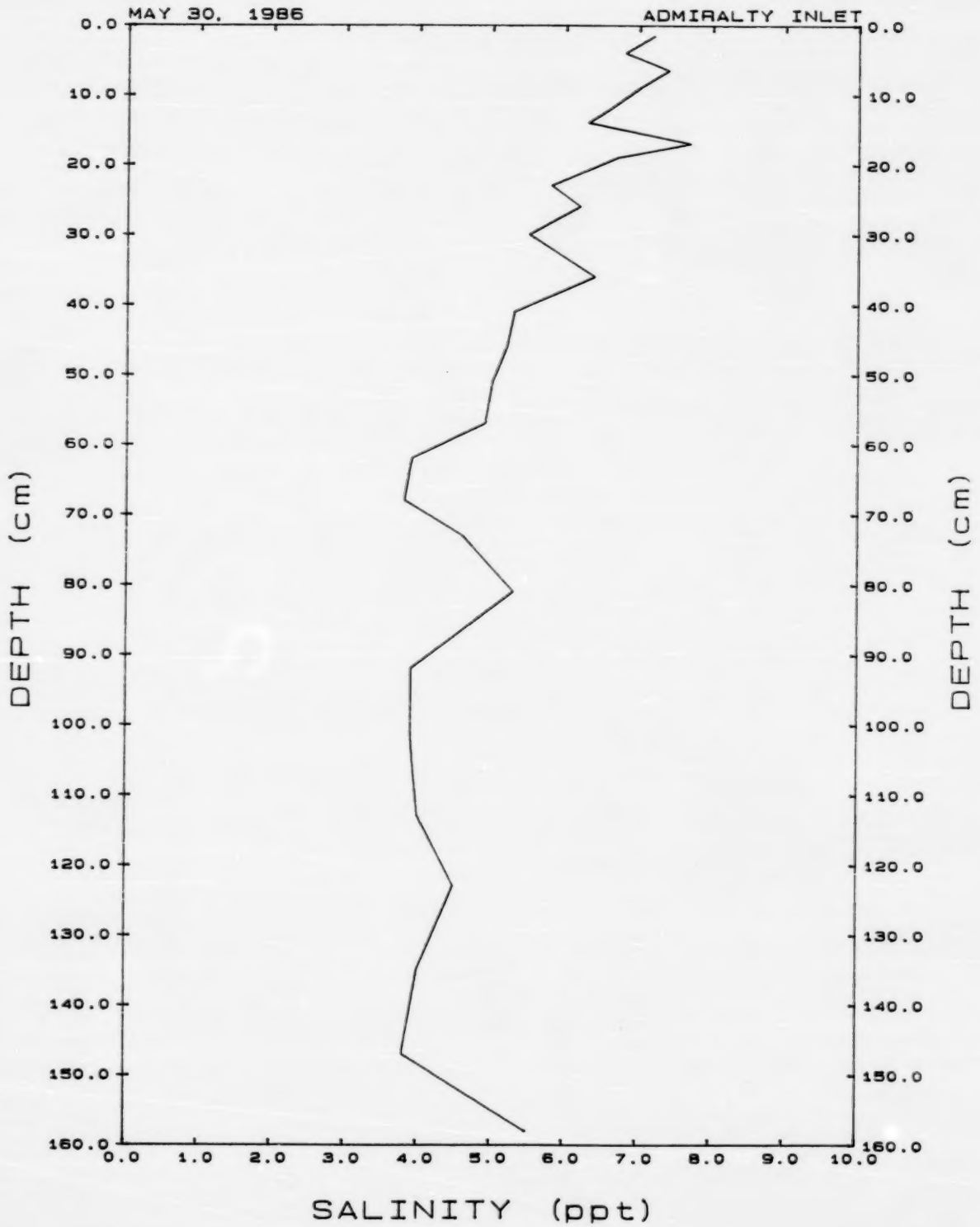
SALINITY VS DEPTH
SITE 9



SAL9

FIGURE B-9

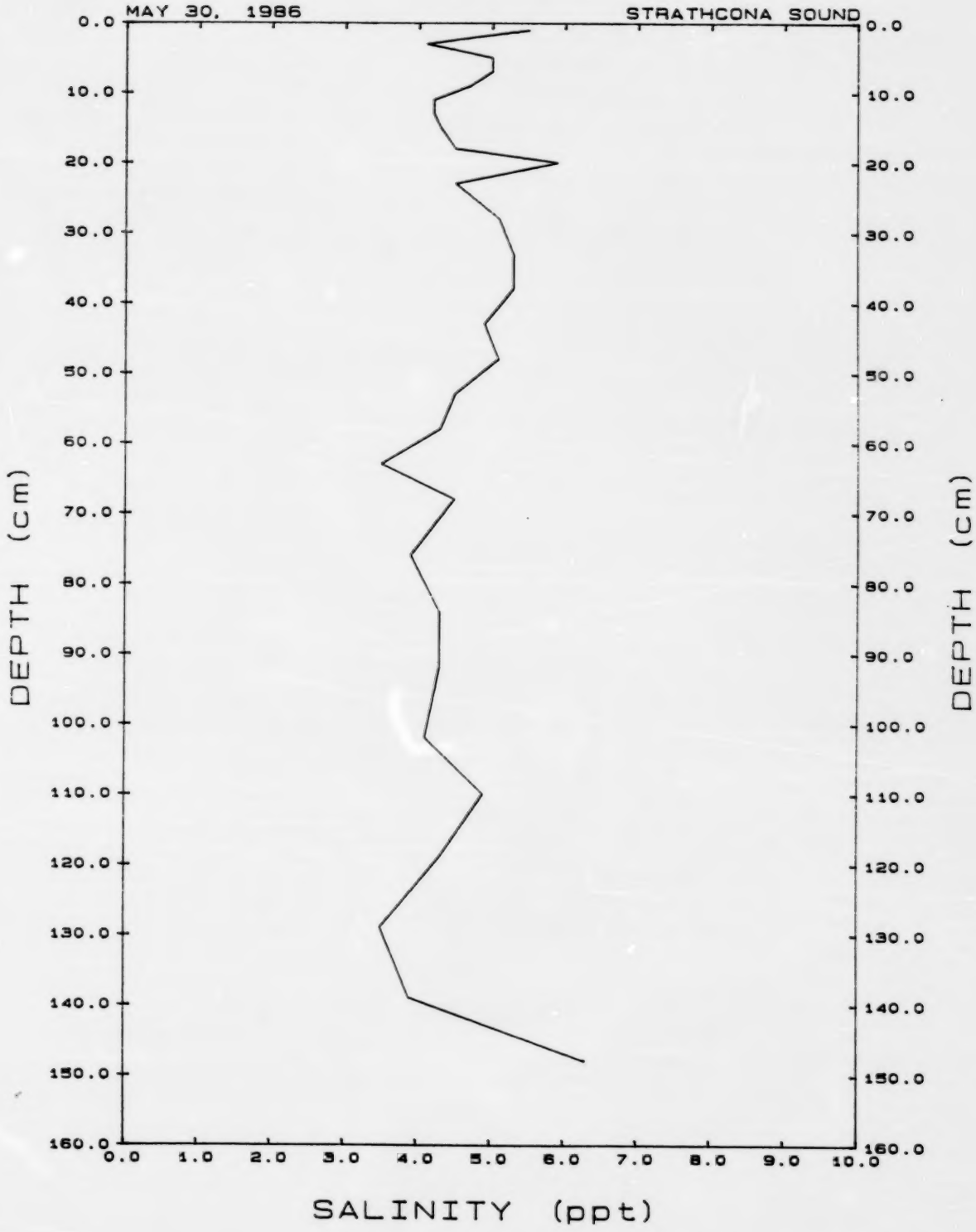
SALINITY VS DEPTH
SITE 10



SAL10

FIGURE B-10

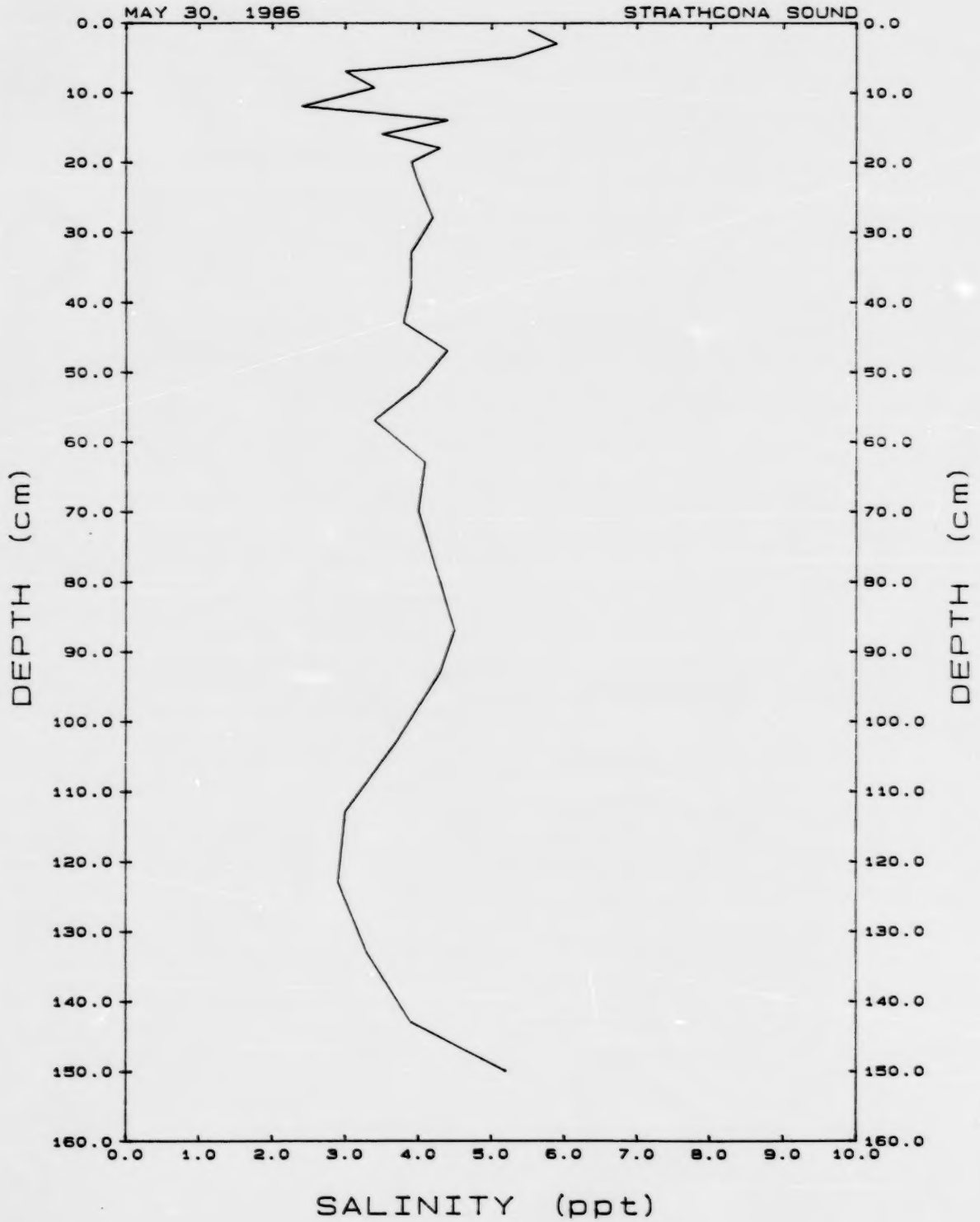
SALINITY VS DEPTH
SITE 46



SAL46

FIGURE B-11

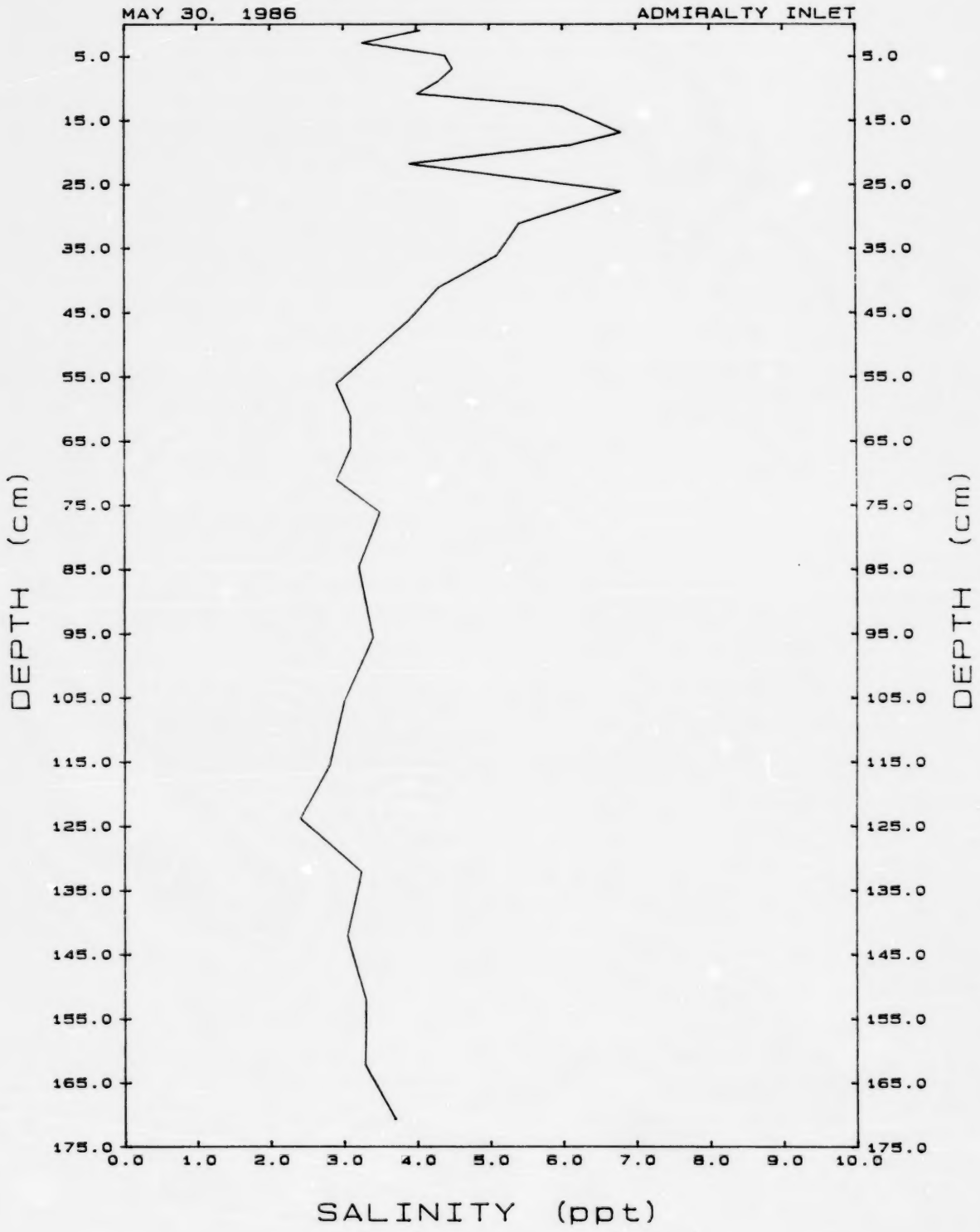
SALINITY VS DEPTH
SITE 51



SAL51

FIGURE B-12

SALINITY VS DEPTH
RIDGE SECTION 3 SOUTH



SAL32